CONTENTS

Appendixes

List of Figures

List of Tables

List of Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
bgs	below ground surface
BH	bore hole
CNTG	compensated neutron tool, model G
DR	dual rotation
ECS	elemental capture spectroscopy
EES	Earth and Environmental Sciences (Division)
ER	Environmental Restoration (Project)
FIP	field implementation plan
FMU	Facility Management Unit
FSF	Field Support Facility (part of the former Environmental Restoration Project)
HSA	hollow-stem auger
hp	horsepower
ID	inner diameter

LANL	Los Alamos National Laboratory
NGS	natural gamma spectroscopy
NTU	nephelometric turbidity unit
OD	outer diameter
P&A	plug and abandon
RC	reverse circulation
RRES	Risk Reduction and Environmental Stewardship Division
SMO	Sample Management Office
SSHASP	site-specific health and safety plan
TA	technical area
TD	total depth
TDL	triple detector lithodensity
TKN	total Kjeldahl nitrogen
TUICPMS	total uranium inductively coupled argon plasma mass spectrometry
UDR	universal drill rig
UR-DTH	under-reaming down-hole-hammer
WGII	Washington Group International, Inc.
WCSF	waste characterization strategy form
XRD	x-ray diffraction
XRF	x-ray fluorescence

Metric to US Customary Unit Conversions

Multiply SI (Metric) Unit	by	To Obtain US Customary Unit
kilometers (km)	0.622	miles (mi)
kilometers (km)	3281	feet (ft)
meters (m)	3.281	feet (ft)
meters (m)	39.37	inches (in.)
centimeters (cm)	0.03281	feet (ft)
centimeters (cm)	0.394	inches (in.)
millimeters (mm)	0.0394	inches (in.)
micrometers or microns (µm)	0.0000394	inches (in.)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.5	acres
square meters (m^2)	10.764	square feet (ft^2)
cubic meters (m^3)	35.31	cubic feet (ft^3)
kilograms (kg)	2.2046	pounds (lb)
grams (g)	0.0353	ounces (oz)
grams per cubic centimeter (g/cm^3)	62.422	pounds per cubic foot (lb/ft^3)
milligrams per kilogram (mg/kg)	1	parts per million (ppm)
micrograms per gram (µg/g)	1	parts per million (ppm)
liters (L)	0.26	gallons (gal.)
milligrams per liter (mg/L)	1	parts per million (ppm)
degrees Celsius (°C)	9/5 + 32	degrees Fahrenheit (°F)

CHARACTERIZATION WELL R-8 COMPLETION REPORT

ABSTRACT

Characterization well R-8 was installed under implementation of the “Hydrogeologic Workplan” (LANL 1998, 59599) under the direction of the former Environmental Restoration Project. Drilling activities were carried out by Washington Group International, Inc., under a subcontract to Los Alamos National Laboratory (the Laboratory). The well is located in Los Alamos Canyon approximately 3300 ft downstream of the confluence with DP Canyon in the northeastern portion of the Laboratory. Well R-8 was designed to provide hydrogeologic and water-quality data on the regional groundwater and to assess the impact of Laboratory activities in the Los Alamos Canyon watershed. Geologic, hydrologic, geochemical, and water-quality information gathered during drilling will contribute to further understanding of the Laboratory’s subsurface hydrogeologic setting, including the locations of possible intermediate perched water zones and the distribution of any contaminants downgradient of Technical Area (TA)-21.

The first borehole (BH1) was cored to a depth of 261 ft and drilled to a depth of 1022 ft using air-rotary drilling methods. BH1 was plugged and abandoned after efforts to retrieve drilling equipment that became lodged in the borehole were unsuccessful. The installation of well R-8 was completed on February 14, 2002, in the second borehole (BH2). Two screened intervals were placed within the regional aquifer, and a Westbay™ multiport system for groundwater sampling was installed inside the well casing.

The stratigraphy encountered during borehole drilling included, in descending order, alluvial sediments, the Otowi Member of the Bandelier Tuff, the Guaje Pumice Bed, upper Puye Formation sediments, Cerros del Rio basalt, and lower Puye Formation sediments. Samples of rock core and drill cuttings were collected for lithologic description and analysis of petrographic, geochemical, and hydraulic properties.

Several intervals of moisture were detected in the upper part of the borehole (within the alluvium, Otowi Member of the Bandelier Tuff, and Guaje Pumice Bed), but they did not produce sufficient water to warrant installation of well screens. The zone of regional groundwater saturation was encountered at a depth of 709 ft and continued down to the bottom of the borehole at 1022 ft. Groundwater samples from the regional aquifer were collected from the borehole for screening analysis for organic and inorganic constituents and radiochemical compounds. Screening results indicate that tritium is present at a slightly elevated level above background in the regional aquifer at this well site.

1.0 INTRODUCTION

This completion report summarizes the planning, site preparation, drilling, well construction, well development, and hydrological testing activities conducted at the R-8 site from September 14, 2001, to February 14, 2002. Well R-8 is located in Los Alamos Canyon approximately 3300 ft downstream of the confluence with DP Canyon in the northeast area of the Laboratory, as shown in Figure 1.0-1. It was installed as part of the hydrogeologic work plan (LANL 1998, 59599), in support of Los Alamos National Laboratory's (LANL's or the Laboratory's) Groundwater Protection Management Program Plan (LANL 1996, 70215).

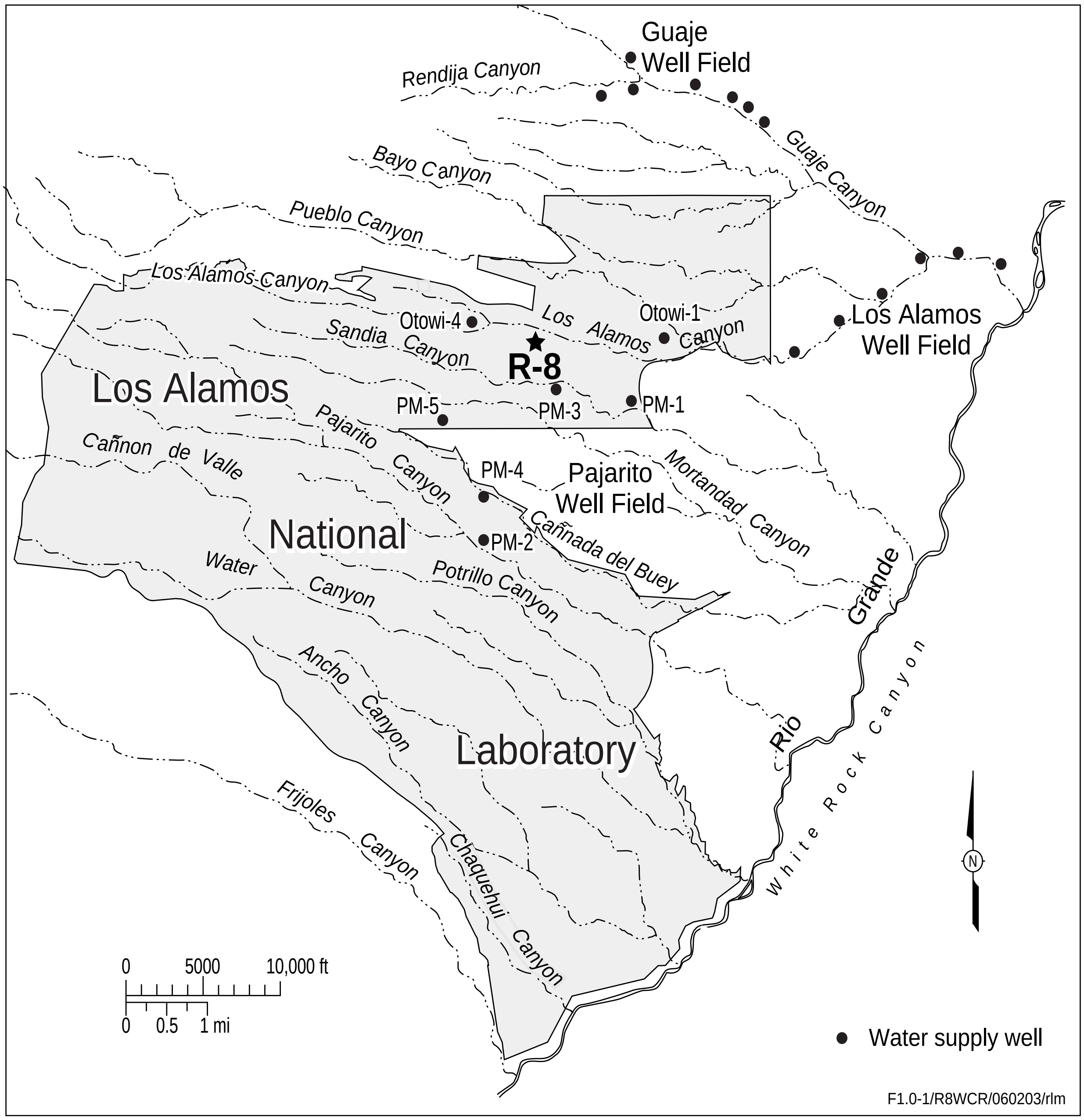


Figure 1.0-1. Map showing location of characterization well R-8

Well R-8 was funded by the Nuclear Weapons Infrastructure, Facilities, and Construction Program and installed by the Laboratory's former Environmental Restoration (ER) Project. Washington Group International, Inc. (WGII), under contract to the Laboratory, was responsible for executing drilling activities.

The information presented in this report was compiled from field reports and activity summaries generated by the Laboratory and subcontractor personnel. Geophysical data provided by Schlumberger, Inc., (Schlumberger) and geodetic survey results are included. Results of these activities are discussed briefly and shown in tables, figures, and appendices contained in this report. Detailed analysis and interpretation of geologic, geochemical, geophysical, and hydrologic data will be included in separate technical documents to be prepared by the Laboratory.

This characterization well will function primarily to investigate the nature and extent of impacts to regional groundwater resulting from Laboratory activities in the Los Alamos Canyon watershed. Water-quality, geochemical, hydrologic, and geologic information gathered during completion will augment knowledge of regional subsurface characteristics and distribution of any contaminants downgradient of Technical Area (TA)-21, a potential source of groundwater contamination. Well R-8 is designed to provide water-quality and water-level monitoring data from the regional aquifer. Data from R-8 will be used to update the sitewide hydrologic and geologic conceptual models for the Laboratory.

2.0 PRELIMINARY ACTIVITIES

WGII received contractual authorization to start administrative preparatory tasks on August 14, 2001. Prior to drilling, WGII prepared a modification to the existing site-specific health and safety plan (SSHASP), No. 273, to include well R-8. WGII also prepared the R-8 waste characterization strategy form (WCSF). The Laboratory prepared the "Field Implementation Plan (FIP) for the Drilling and Testing of LANL Regional Aquifer Well R-8" to delineate drilling and sampling plans and to guide the execution of R-8 field activities (LANL 2001, 71282.1). The host facility, Facility Management Unit (FMU) 80, authorized a Facility Tenant Agreement to provide access and security control for R-8 activities. Appendix A compares characterization activities that were performed at R-8 with the planned activities described in the hydrogeologic work plan (LANL 1998, 59599) and the R-8 field implementation plan (FIP) (LANL 2001, 71282.1).

A readiness review meeting was held on September 6, 2001, to discuss all administrative documents, permits, agreements, and plans pertaining to the R-8 project. The Groundwater Investigations Focus Area project leader signed the readiness review checklist on September 13, 2001, authorizing the commencement of fieldwork.

S. G. Western Construction Company was subcontracted by WGII to conduct predrilling site preparation. Activities included clearing the site and trimming trees, constructing an access road and a drill pad, and constructing a lined cuttings-containment area. Site preparation was completed from September 14 to September 24, 2001.

Initially the site was cleared of trees, stumps, and large boulders. Parts of the canyon road were graded and improved. The drill pad and two entry roads were constructed by grading the selected area and compacting the subgrade. A 90,000-gal.-capacity containment area, 20 ft wide by 60 ft long, was excavated along the south boundary of the drill pad and lined with a 6-mil polyethylene liner for storing drilling fluids and cuttings. An area large enough to contain two 20,000-gal. fluid-storage trailers was prepared along the northeast corner of the drill-pad site to provide additional storage for drilling fluids. Placing Geo-Grid™ geotextile fabric and distributing and grading a layer of base-course gravel over the compacted subgrade completed drill pad construction. Safety barriers and signs were installed around the cuttings-containment area and at the site entrance. Office and supply trailers, generators, and safety lighting equipment were moved onto the site prior to Phase I drilling.

3.0 SUMMARY OF DRILLING ACTIVITIES

R-8 drilling was performed in two phases by Dynatec Drilling Company, Inc. (Dynatec). The goals of Phase I drilling were to collect continuous rock core samples for geologic characterization and to collect samples from the upper section of the borehole for moisture, anion, stable isotope, and tritium distribution analyses. Planned total depth (TD) for Phase I drilling was contingent upon the depth of core barrel refusal. Equipment and fabrication support for drilling activities were provided by the ER Project's Field Support Facility (FSF).

The objectives of Phase II drilling were to log and collect cuttings of encountered geologic formations, collect water samples from perched and regional groundwater zones, and provide a borehole for geophysical measurements and for installing a monitoring well in the regional aquifer. Air-rotary methods were used during Phase II drilling to a TD of 1022 ft bgs. However, expansive clays above the drill bit assembly and a series of mishaps by the WGII/Dynatec drill team, coupled with Dynatec's inability to successfully retrieve the lost drill-bit assembly, led to the Laboratory's concern about the long-term viability of a well installation in BH1 and a decision to plug and abandon (P&A) the borehole. A second borehole, BH2, located 63 ft west and hydraulically upgradient of BH1, was drilled by air-rotary methods to replace the abandoned borehole.

Sections 3.1 and 3.2 discuss drilling activities for the first and second boreholes, respectively. Figure 3.0-1 summarizes drilling activity data and depicts groundwater and geologic conditions encountered.

3.1 Borehole BH1 Drilling Activities

Prior to P&A, drilling at BH1 included Phase I coring, Phase II air-rotary drilling, and borehole geophysics. After extensive efforts to recover stuck drill tools, BH1 was plugged and abandoned. Figure 3.1-1 shows the chronology of drilling and other related on-site activities at BH1.

3.1.1 Phase I Drilling at BH1

Phase I drilling activities at BH1 occurred from September 25 to October 3, 2001. Dynatec provided a Foremost™ Universal Drill Rig (UDR) 1000 equipped with a wire-line core retrieval system. A 5-ft-long core barrel was used to collect 3-in.-diameter core samples. The core barrel was fitted with two 6-in.-long Lexan tubes at the base of each core sleeve. The primary goal of Phase 1 was to collect core samples from the surface through the alluvium and Bandelier Tuff. The FIP called for continuous coring operations into the Cerros del Rio basalt or until core refusal occurred. Groundwater samples were to be collected during coring operations if significant water was encountered in bedrock units below the alluvium.

On September 25, 2001, Dynatec mobilized its drill rig and support equipment to the R-8 site and began coring operations (Figure 3.1-1). The borehole was initially advanced with a 4-in.-outside diameter (OD) soft-rock core bit from 0 to 30 ft below ground surface (bgs). Continuous core samples were collected through unconsolidated alluvium and into the Otowi Member of the Bandelier Tuff. Then the cored hole was reamed with a 5.375-in. tricone bit for a temporary 5-in.-diameter steel surface casing installed to a depth of 30 ft bgs to prevent hole collapse.

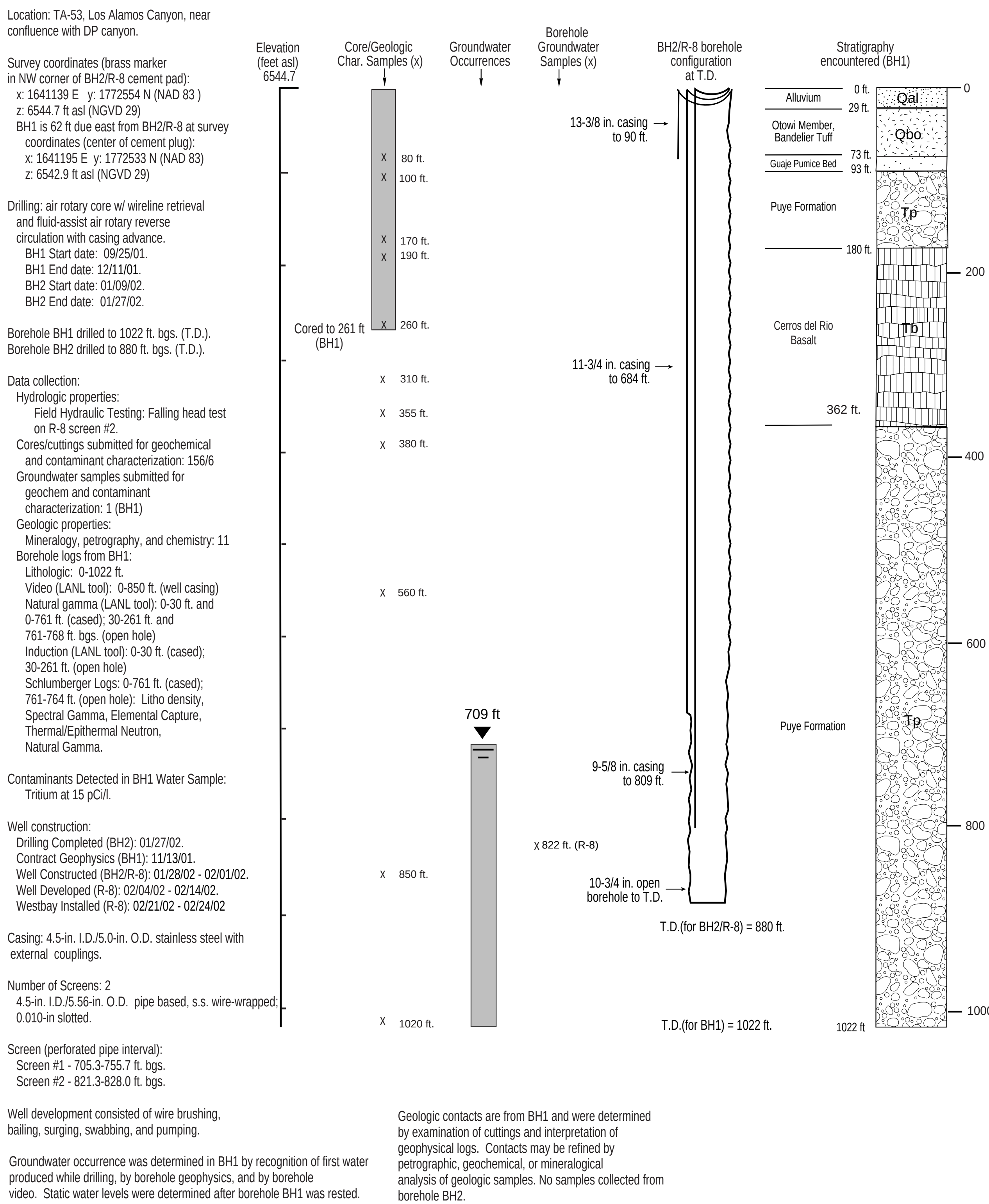


Figure 3.0-1. Well summary data sheet for characterization well R-8

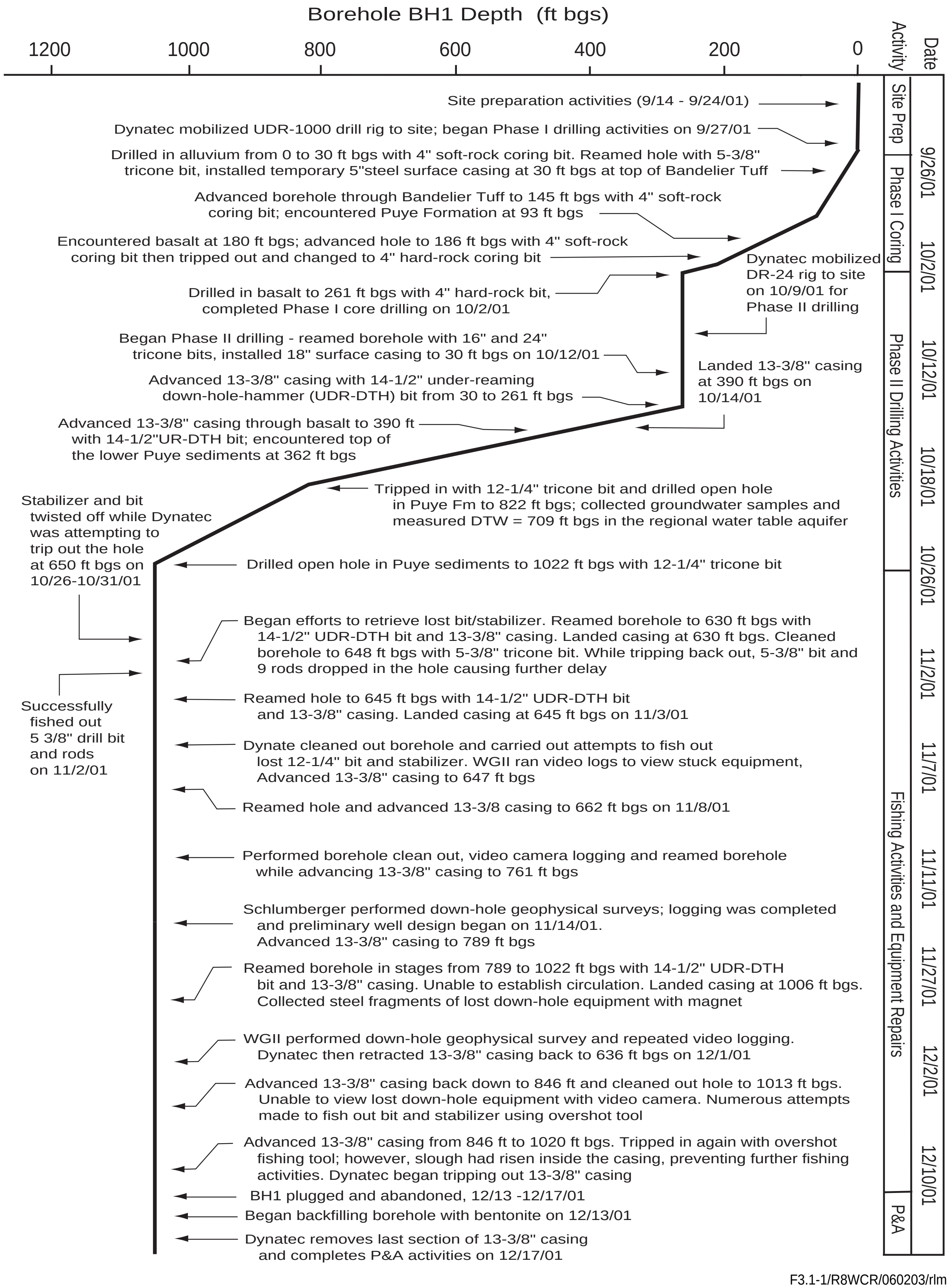


Figure 3.1-1. Operations chronology diagram for BH1

Core drilling resumed using the 4-in. soft-rock core bit through the Otowi Member of the Bandelier Tuff, the Guaje Pumice Bed, and the upper Puye Formation, eventually encountering difficult coring conditions in the Cerros del Rio basalt at approximately 180 ft bgs. After penetrating 9 ft into the basalt, Dynatec tripped out and changed to a 4-in.-OD hard-rock core bit. Coring proceeded within the basalt to a depth of 261 ft bgs and was terminated on October 1, 2001. The penetration rate had slowed dramatically, in part because geologic conditions (scoria deposits) had caused two hard-rock core bits to fail in consecutive drill shifts.

3.1.2 Phase II Drilling at BH1

Dynatec conducted Phase II drilling with a Foremost™ Dual Rotary (DR)-24 drill rig equipped with a fluid-assisted air-rotary reverse circulation (RC) system. The goals of Phase II drilling were to produce cuttings samples of the geologic formations, collect groundwater samples when appropriate, and provide a stable borehole for geophysical logging and well installation. During drilling operations, cuttings samples for geologic characterization were collected at 5-ft intervals from the RC system's fluid-discharge trough.

During Phase II, open-hole and casing-advance drilling methods were used with various bit types and sizes appropriate for existing formation and drilling conditions. Air-rotary drilling was assisted at times with municipal water mixed with polymer additives, such as EZ-MUD® and QUIK-FOAM® to improve drilling lubrication and facilitate cuttings removal from the borehole.

Phase II drilling began on October 12, 2001, first by removing the temporary 5-in. surface casing and then reaming the cored borehole using a 24-in. quadcone reamer bit (see Figure 3.1-1). An 18-in. steel surface casing was advanced to a depth of 30 ft bgs and cemented in place. After surface casing was set, BH1 was drilled from 30 ft to 390 ft bgs using a 14.50-in. under-reaming down-hole hammer (UR-DTH) bit while advancing 13.375-in. drill casing. The 13.375-in. casing was landed in the Puye Formation at 390 ft bgs. BH1 then was advanced open-hole with a 14.5-in. tricone bit to a depth of 402 ft, when drilling was halted after a top head drive on the DR-24 drill rig broke. Repairs were made and drilling resumed on October 17, 2001. The borehole was advanced to a depth of 822 ft bgs, when on October 19, 2001, the deck engine on the DR-24 failed. Repairs took six days; on October 25, 2001, drilling resumed with borehole advancement to a depth of 1022 ft bgs. The drillers decided to switch to casing-advance methods when they encountered flowing sands. Dynatec began to trip out the drill string to make the conversion to casing-advance with 11.75-in. drill casing.

While pulling the assembly out of the borehole, the drillers experienced very tight borehole conditions in the interval between 680 to 750 ft bgs and could not work the drill-bit assembly beyond this interval. From October 26 to 30, 2001, Dynatec worked to free the drill assembly while continuing to repair the drill rig. On October 31, 2001, Dynatec retrieved all the drill pipe; however, the drillers had twisted off the drill-bit assembly and left the stabilizer, the air-exchange sub, and the bit in the borehole. Fishing operations commenced on October 31, 2001. By November 2, 2001, Dynatec had advanced 13.375-in casing downhole over the lost drill-bit assembly. A 5.375-in. tricone bit was advanced to the top of the assembly to circulate out material that had caved in on top of the stuck drill-bit assembly.

As it cleaned out this portion of the borehole, Dynatec tripped out the 5.375-in. tricone bit to prepare for recovery activities. However, before tripping out the entire drill string, the driller dropped 180 ft of the drill rods and bit. The drill string fell approximately 500 ft and impacted the stuck drill-bit assembly. WGII reported the incident to the Laboratory, and Dynatec immediately began fishing operations on the dropped pipe. The 180 ft of pipe and a portion of the stabilizer was recovered; however, the lower end of the drill rod string was significantly damaged. The amount of damage to the remaining stabilizer could not be assessed fully. Fishing activity continued to November 5, 2001, without success. Optimistic that recovery could be achieved, WGII/Dynatec continued fishing until November 12, 2001.

Borehole geophysical logging was conducted on November 13, 2001. A well design was drafted on November 14 and 15, 2001, based on speculation that the stuck bit assembly was located at a depth below the potential screened interval. However, the Laboratory was concerned about the unconfirmed location of the bit, the potential long-term impact to water quality if the stuck materials were left in place, and the potential instability of constructing a well on top of approximately 200 ft of slough in the bottom of the borehole. Given these concerns and uncertainties, well installation work was halted.

On November 15, 2001, all R-8 fieldwork was suspended, and on November 16, 2001, the Laboratory issued a Notice of Cure to WGII instructing the contractor to provide the Laboratory with a borehole that would be free from extraneous objects in which to install the R-8 well. The option was left up to WGII either to remedy the existing BH1 borehole (i.e., remove all foreign objects stuck in the borehole) or to plug and replace with an offset boring upgradient of BH1, using the existing drill pad.

WGII prepared its plan to cure from November 21 to 25, 2001. On November 26, 2001, WGII began the cure by continuing with fishing operations. On November 28, 2001, the drillers thought they had made contact with the lost bit assembly; thus, WGII requested additional time to continue fishing. On November 30, 2001, WGII again requested more time to continue with fishing operations. Casing was advanced from 911 to 1022 ft, the former TD of the borehole, without making contact with the bit assembly. At this time, WGII reported to the Laboratory that the lost bit was probably located at 786 ft, the last reported contact. WGII requested to use the Laboratory's resistivity tool to confirm the location of the lost bit assembly. The resistivity tool detected an anomaly from 764 to 761 ft.

On December 3, 2001, WGII requested an extension until December 4, 2001, to make another recovery attempt. However, upon maneuvering the casing over the top of the bit assembly at 764 ft, Dynatec reported that the bit had loosened and presumably fallen to the bottom of the borehole. WGII prepared to make another attempt by tripping the casing back to the bottom of the boring. On December 4, 2001, WGII reported that it had located the top of the drill-bit assembly at 1013 ft. On December 5, 2001, WGII reported that the latest recovery attempt had failed, and it requested permission to complete the well without satisfying the Notice to Cure. The request was denied. Believing that the wrong size overshot tool had been used on previous attempts, on December 7, 2001, WGII requested that it be allowed another attempt to recover the lost bit assembly. On December 11, 2001, after using a different size overshot tool, WGII reported to the Laboratory that it was unsuccessful at recovering the lost drill-bit assembly. WGII began P&A activities on BH1 after failing to provide a cure consistent with the Laboratory's Notice to Cure. Additionally, the Laboratory had technical concerns about lost and damaged portions of the drill-bit assembly, the stability of the borehole, and potential formation damage given the repeated fishing attempts in the borehole.

3.1.3 BH1 Plugging and Abandonment

P&A activities at BH1 were carried out from December 13 to December 17, 2001. Prior to backfilling, the bottom of the borehole was measured at 983 ft bgs, indicating 39 ft of accumulated slough. BH1 was initially backfilled from 983 to 696 ft bgs with bentonite pellets. Sloughing occurred from 696 to 644 ft bgs. The borehole was then backfilled from 644 to 76 ft bgs using a 3-to-1 ratio of washed gravels and .375-in. bentonite chips. P&A activities were completed by grouting the interval from 76 ft bgs to ground surface using a mixture of Portland cement powdered bentonite (2% by volume). Figure 3.1-2 shows the as-built configuration of the abandoned borehole.

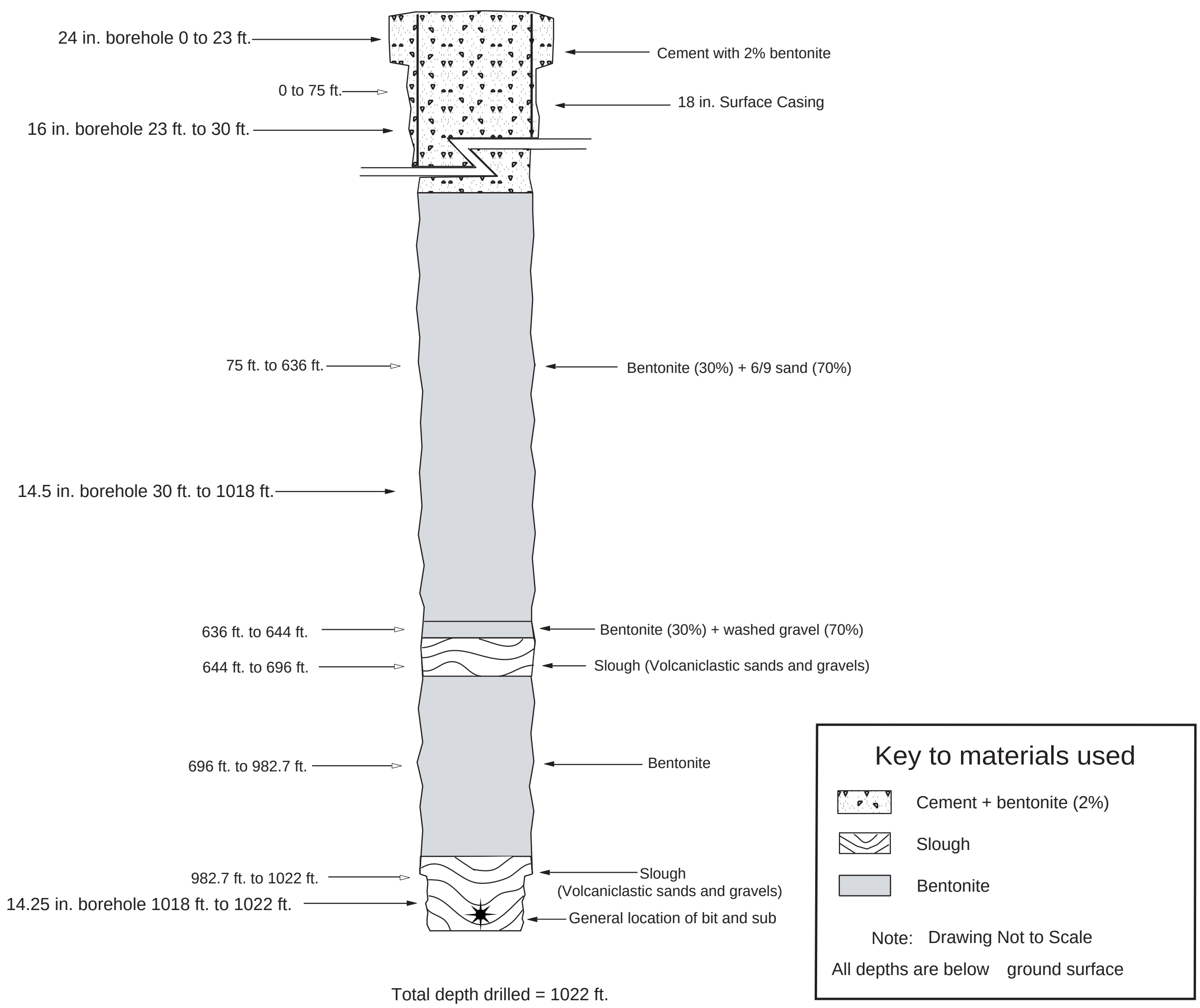


Figure 3.1-2. Abandonment diagram for BH1

3.2 BH2 Drilling Activities

BH2 was drilled for the purpose of installing characterization well R-8. The new location was selected within the boundary of the original drill pad, 63 ft west and hydraulically upgradient of the abandoned borehole BH1. Because characterization activities had been completed at BH1, no core or drill cuttings were collected at BH2. A diagram showing the chronology of drilling and other on-site activities is presented in Figure 3.2-1.

Drilling of BH2 was conducted using the DR-24 rig, along with similar equipment, air-rotary methods, materials, and potable water supply as used at BH1. Dynatec mobilized additional drill casing and equipment to the site on January 8, 2002. Drilling began on January 9, 2002, and was completed on January 27, 2002.

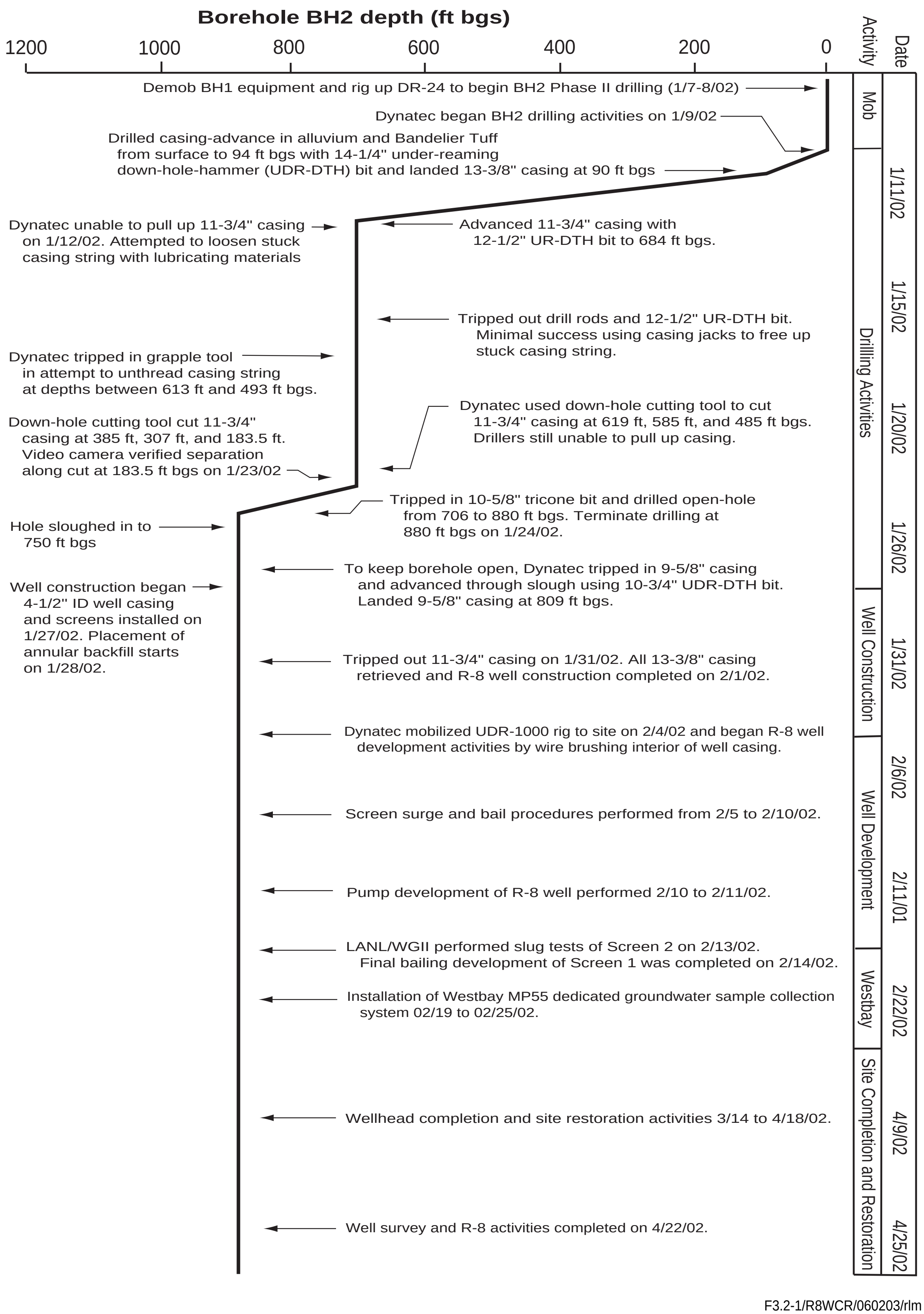


Figure 3.2-1. Operations chronology diagram for BH2

Casing-advance drilling commenced at BH2 using a 14.25-in. UR-DTH bit along with 13.375-in. drill casing with casing shoe. The 13.375-in. casing was landed at 90 ft bgs (Figure 3.1-2). Dynatec continued casing-advance drilling from 90 to 706 ft bgs using a 12.5-in. UR-DTH bit while advancing 11.75-in. drill casing. At a depth of 706 ft bgs, Dynatec encountered the same expansive clays that were present in BH1. Puye sediments tightened around the 11.75-in. drill casing, inhibiting its advancement or retrieval.

Efforts to loosen and remove the casing began on January 12, 2002. To assist in lubricating the casing, a water and EZ-MUD® mixture was pumped down the casing annulus. Other efforts to loosen the casing included pouring industrial-grade glass beads down the casing annulus. After extensive discussion with the Laboratory's drilling consultant, a decision was made on January 16, 2002, to install a jack cellar and use hydraulic jacks to increase the lifting or pull-back capacity of the DR-24 rig. Further attempts to pull back the casing string were unsuccessful, including efforts to use a grapple spear and retract hammer. Efforts to unthread the drill casing joints near the bottom of the casing string were also unsuccessful. On January 19, 2002, Knight Fishing Services was brought in to cut the casing string at the lowest depth and at a point above the stuck portion of the casing. The contractor made casing cuts at depths of 619, 585, 485, 385, 307, and 184 ft. Attempts were made after each cut to free the casing. The casing was not freed until after the cut at 184 ft . A borehole video survey on January 23, 2002, verified that the 11.75-in. casing had been successfully cut and removed at a depth of 184 ft, leaving the remaining casing segment from 184 to 684 ft bgs in the hole.

Dynatec resumed drilling open-hole using a 10.625-in. tricone bit and advanced the borehole from 684 to 862 ft bgs. Subsequent borehole sloughing made it necessary to return to casing-advance drilling.

Drilling through the sloughed borehole interval resumed with a 10.75-in. UR-DTH bit while advancing 9.625-in. drill casing. The casing was landed at 809 ft bgs. The borehole was advanced using open-hole techniques using the 10.625-in. UR-DTH bit to a depth of 880 ft bgs. On January 27, 2002, drilling activities ceased with TD of BH2 at 880 ft bgs.

4.0 SAMPLING AND ANALYSIS OF DRILL CORE, CUTTINGS, AND GROUNDWATER

During drilling operations at R-8 (BH1), core samples and drill cuttings were collected as specified in the R-8 FIP (LANL 2001, 71282.1). As drilling conditions permitted, a sufficient quantity of borehole material was collected by RC at 5-ft intervals. A portion of the cuttings was sieved (at >#10 and >#35 mesh) and placed in chip-tray bins along with an unsieved portion. These chip trays were studied to determine lithological characteristics and were used to prepare the lithologic logs. The remaining cuttings were sealed in ziplock bags and set in core boxes for curation. No cuttings samples were submitted for contaminant analysis. Prior to curation, 12 samples were removed for mineralogic, petrographic, and geochemical analysis.

During drilling operations, perched groundwater was encountered within the Guaje Pumice Bed and the top of the Puye Formation between 30 and 96 ft bgs. This zone became dry at the time of sampling as a result of a leak through the borehole to the Cerros del Rio basalt. No water samples were collected from this perched zone. Regional groundwater was encountered at 822 ft bgs on October 19, 2001.

Samples of core and cuttings were collected from R-8 (BH1) and analyzed for tritium using liquid scintillation for characterization purposes (Table 4.0-1). Twenty-three samples of core were collected from the vadose zone during drilling. Approximately 500 to 1000 g of core or cuttings samples were placed in appropriate sample jars in protective plastic bags before they were shipped to Paragon Analytics, Inc., in Fort Collins, Colorado.

Table 4.0-1
Core-Sample Tritium Activity and Moisture Content, Characterization Well R-8

Depth (ft)	Tritium Activity (pCi/L)	Moisture Content (wt %)	Hydrogeologic Unit
45.25	54.7	21.9	Otowi Member
50.25	47.4	23.3	Otowi Member
55.95	330	24.8	Otowi Member
59.25	525	32.7	Otowi Member
65.95	262	26.6	Otowi Member
74.75	368	28.5	Guaje Pumice Bed
79.95	230	30.5	Guaje Pumice Bed
84.75	556	42.1	Guaje Pumice Bed
88.2	98.4	16.5	Guaje Pumice Bed
91.75	231	20.5	Guaje Pumice Bed
100.75	123	18.2	Puye Formation
104.75	73.4	18.7	Puye Formation
112.75	53.2	13.2	Puye Formation
118.25	72.2	10.0	Puye Formation
122.25	159	13.7	Puye Formation
125.75	433	20.8	Puye Formation
128.75	272	16	Puye Formation
133.25	56.7	7.4	Puye Formation
135.75	158	14.1	Puye Formation
139.75	159	16.1	Puye Formation
143.75	71.3	12.7	Puye Formation
146.75	99.4	19.9	Puye Formation

Radionuclide activities in core samples were analyzed by alpha spectrometry (americium-241; plutonium-238; plutonium-239, 240; uranium-234; uranium-235; and uranium-238); gamma spectrometry (cesium-137 and gamma-emitting isotopes); gas-proportional counting (strontium-90), and liquid scintillation (tritium) at Paragon Analytics, Inc.

The following equation was used to convert the activity of tritium present in the pore water from picocuries per gram to picocuries per liter:

$$\text{pCi/L} = (\text{pCi/g})(1 \text{ g } H_2O/1 \text{ ml } H_2O)(\theta/1 - \theta)(10^3 \text{ ml/L})$$

where θ = gravimetric moisture content and the pore water density are assumed equal to 1.

Gravimetric moisture content was measured at Paragon Analytics, Inc.

Geochemistry of Sampled Waters

One regional aquifer water sample was collected from the undeveloped borehole during drilling and was analyzed for a limited suite of constituents. The sample was collected at a depth of 822 ft primarily to determine if potential contaminants had been introduced from upper horizons into the regional aquifer during drilling operations. Major potential contaminants of concern at R-8 include mobile solutes such as perchlorate, nitrate, uranium, and tritium and adsorbing radionuclides consisting of americium-241, cesium-137, plutonium-238, plutonium-239, 240, strontium-90, and uranium. The sample contained some drilling fluids (EZ-MUD® and other additives) used for lubricity. The sample collected is not representative of purely native groundwater but provides baseline groundwater compositions that were present during drilling.

The groundwater sample from R-8 that was analyzed for inorganic and organic chemicals and tritium was collected by circulating water through the drill stem at a depth of 822 ft. Temperature, turbidity, pH, and specific conductance were not determined on the site. Both filtered (metals, trace elements, and major cations and anions) and nonfiltered (radionuclides and stable isotopes) samples were collected for chemical and radiochemical analyses. Aliquots of the samples were filtered through a 0.45-µm Gelman filter. Samples were acidified with analytical-grade nitric acid to a pH of 2.0 or less for metal and major ion analyses. The groundwater sample collected in the field was stored at 4°C until it was analyzed. Alkalinity was determined in the laboratory using standard titration techniques, which may approximate field conditions because of sample degassing, including carbon dioxide gas.

The groundwater sample was analyzed by the Hydrology, Geochemistry, and Geology group of the Earth and Environmental Science (EES) Division. Ion chromatography (IC) was the analytical method for bromide, chloride, fluoride, nitrate, nitrite, oxalate, perchlorate, phosphate, and sulfate. Ammonium was analyzed by ion selective electrode (ISE), whereas mercury was analyzed by cold vapor atomic absorption (CVAA). Inductively coupled (argon) plasma emission spectroscopy (ICPES) was used to analyze for calcium, magnesium, potassium, silica, and sodium. Aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, selenium, silver, thallium, vanadium, uranium, and zinc were analyzed by inductively coupled (argon) plasma mass spectrometry (ICPMS).

Radionuclide activity in groundwater was determined by direct counting for tritium; alpha spectrometry for americium, plutonium, and uranium isotopes; and gamma spectrometry for cesium-137 and other gamma-emitting isotopes. Contract laboratories performing this work were Paragon Analytics, Inc. (radionuclides) and the University of Miami (low-level tritium). Stable isotopes of oxygen (oxygen-18/-16 ratio) and hydrogen (delta deuterium) were analyzed by Geochron Laboratories (Cambridge, Massachusetts) using isotope ratio mass spectrometry (IRMS).

The precision limits (analytical error) for major ions and trace elements generally were less than ±10% using ICPES and ICPMS. Core samples were collected from R-8 (BH1) and analytical results (inorganics and radionuclides) shall be provided in an investigative report.

Results of screening analyses for the groundwater sample collected from the borehole in R-8 (BH1) are provided in Tables 4.1-1 and 4.1-2. Based on the analytical results for the sample, it appears that tritium is present at a slightly elevated level above background in the regional aquifer at this well site.

5.0 BOREHOLE GEOPHYSICS

WGII (using Laboratory tools) and Schlumberger performed borehole logging operations at BH1 and BH2.

Table 4.1-1
Hydrochemistry of Regional Aquifer Samples, Characterization Well R-8 (filtered)

Depth (ft)	**822**
Geologic Unit	**Puye Formation**
Date Sampled	**10/19/01**
pH (laboratory)	8.13
Alkalinity (mg $CaCO_3$/L)	91.0
Al (mg/L)	0.06
NH_4 (as N) (mg/L)	0.19
Sb (mg/L)	[0.0002], U
As (mg/L)	0.0011
B (mg/L)	0.020
Ba (mg/L)	0.093
Be (mg/L)	[0.001], U
Br (mg/L)	0.01
Cd (mg/L)	[0.001], U
Ca (mg/L)	20.5
Cl (mg/L)	4.43
ClO_4 (mg/L)	[0.002], U
Cr (mg/L)	[0.001], U
Co (mg/L)	[0.001], U
Cu (mg/L)	0.0013
F (mg/L)	0.53
Fe (mg/L)	0.02
Pb (mg/L)	[0.001], U
Mg (mg/L)	3.84
Mn (mg/L)	0.03
Hg (mg/L)	0.00015
Mo (mg/L)	0.0023
Ni (mg/L)	[0.001], U
NO_3 (mg/L) (as N)	0.69
NO_2 (mg/L) (as N)	[0.01], U
C_2O_4 (mg/L) (oxalate)	0.05
PO_4 (mg/L) (as P)	[0.01], U
K (mg/L)	2.91
Se (mg/L)	[0.001], U
Ag (mg/L)	[0.001], U
Na (mg/L)	13.5

Table 4.1-1 (continued)

Depth (ft)	**822**
Geologic Unit	**Puye Formation**
Date Sampled	**10/19/01**
SiO_2 (mg/L)	76.4
SO_4 (mg/L)	4.10
Tl (mg/L)	[0.001], U
U (mg/L)	[0.001], U
V (mg/L)	0.008
Zn (mg/L)	0.001
TDS (mg/L) (calculated)	241

Note: U = Not detected. Silica concentrations were calculated from measured silicon (ICPES).

Table 4.1-2
Hydrochemistry of Regional Aquifer Samples, Characterization Well R-8 (nonfiltered)

Depth (ft)	**822**
Geologic Unit	**Puye Formation**
Date Sampled	**10/19/01**
Tritium (pCi/L)	16
Am-241 (pCi/L)	[0.02], U
Cs-137 (pCi/L)	[–1.04], U
Pu-238 (pCi/L)	[–0.003], U
Pu-239,240 (pCi/L)	[0.003], U
U-234 (pCi/L)	1.16
U-235 (pCi/L)	[0.03], U
U-238 (pCi/L)	0.80
TOC (mgC/L)	—
δD (‰)	–75
δ^{18}O (‰)	–10.4

Notes: 1. U = not detected.
2. Dash = not analyzed.
3. ‰ = permil.
4. TOC = total organic carbon.

5.1 Geophysical Logging Using Laboratory Tools

Between October 4, 2001, and January 23, 2002, WGII ran natural gamma, induction, and video camera logs using down-hole tools provided by the Laboratory. The gamma and induction logs were run to provide lithologic and stratigraphic information to complement data gathered from core and cuttings; the video logs were run to troubleshoot drilling problems. Table 5.1-1 summarizes the borehole and well logs run in boreholes BH1 and BH2.

Table 5.1-1
Borehole and Well Logging Surveys Conducted in BH1 and BH2 at Characterization Well R-8

Surveyor	Date	Hole	Method	Cased Footage	Open-Hole Footage	Remarks
WGII/LANL	10/3/01	BH1	Video	0–30	30–261	Conducted to observe core hole conditions
WGII/LANL	10/4/01	BH1	Natural gamma; induction	0–30	30–261	Conducted after completion of Phase I drilling
WGII/LANL	10/31–11/2/01	BH1	Video	0–630	630–648	Two surveys conducted to view drilling equipment stuck in borehole
WGII/LANL	11/4–11/6/01	BH1	Video	0–645	645–647	Four surveys conducted to view drilling equipment stuck in borehole
WGII/LANL	11/7–11/9/01	BH1	Video	0–647	647–686	Three surveys conducted to view drilling equipment stuck in borehole
WGII/LANL	11/13/01	BH1	Natural gamma	0–761	761–768	Natural gamma survey performed inside cased borehole
Schlumberger	11/13/01	BH1	Logging suite[a]	0–761	761–764	Schlumberger borehole logging conducted in cased borehole prior to plugging and abandonment
WGII/LANL	11/29–12/11/01	BH1	Video	0–1018	741–1022	Fourteen surveys conducted to assist Dynatec's efforts to fish out drilling equipment stuck in borehole
WGII/LANL	1/19/02	BH2	Video	0–686	686–706	Two surveys conducted to view casing unthreaded at 74 ft bgs
WGII/LANL	1/22–1/23/02	BH2	Video	0–686	686–862	Three surveys conducted to verify casing cut at 485 ft and 183.5 ft bgs
WGII/LANL	1/28/02	Well R-8	Video	NA[b]	NA	Survey conducted to inspect condition of well casing and screens

[a] Schlumberger suite of geophysical logging surveys included lithodensity, spectral gamma, elemental capture, thermal-epithermal neutron, and natural gamma.
[b] NA = Not applicable.

Two natural gamma logs were run. Natural gamma logs have proven successful in discriminating between local geologic units that contain varying concentrations of uranium, thorium, and potassium. The gamma tool is also used to verify placement of annular material in the completed well. The first gamma log was run inside the 18-in. surface casing from surface to 30 ft bgs and in open-hole conditions from 30 to 261 ft bgs shortly after Phase I core drilling was completed. An induction log was run in borehole BH1 concurrently with the first Laboratory gamma log. A second gamma log was run inside the 13.375-in. drill casing from surface to 761 ft bgs and in open-hole conditions from 761 to 768 ft bgs. Measurements of natural gamma activity were obtained every 0.1 ft as the logging tool was raised up in the hole at a rate of about 15 ft/min.

Numerous video logs were run in BH1 and BH2 (Table 5.1-1). Most of these were made in BH1 to assist Dynatec's efforts to fish out and retrieve down-hole drilling equipment and to verify that drill casing had been successfully cut down-hole. One video log was also conducted as a quality control procedure to inspect the condition of the stainless steel well casing and screens installed in completed well R-8. Appendix B is a video log of the open borehole (on CD inside back cover of this report).

5.2 Schlumberger Geophysical Logging

Schlumberger conducted borehole geophysical logging in BH1 on November 13, 2001. Schlumberger performed logging surveys inside the 13.375-in. drill casing from the surface to 761 ft bgs and in open-hole conditions from 761 to 764 ft bgs (Table 5.1-1). No Schlumberger logging services were used in BH2.

The primary purpose of Schlumberger's logging activities was to characterize conditions in the hydrogeologic units penetrated by BH1, with an emphasis on determining moisture distribution, identifying perched groundwater and regional water-table zones, and obtaining lithologic and stratigraphic data. This information was used during the design phase of well screen placement and construction.

The Schlumberger suite of geophysical logging tools included the following:

- Triple Detector Litho-Density (TLD™). Measures bulk density related to porosity of a formation, photoelectric effect related to lithology, and borehole diameter using a single-arm caliper.
- Natural Gamma Spectroscopy (NGS™). Measures gross natural and spectral gamma-ray activity (including uranium, thorium, and potassium concentrations) in open- and cased-hole conditions to help characterize geology and lithology.
- Elemental Capture Spectroscopy (ECS™). Measures elemental weight percent concentrations of a variety of elements (e.g., calcium, iron, gadolinium) to characterize formation mineralogy, lithology, and water content.
- Compensated (thermal-epithermal) Neutron Tool, Model G (CNTG™). Measures volumetric water content outside the casing to evaluate formation moisture content and porosity.

Additionally, a calibrated natural gamma tool was used and gross natural gamma-ray activity was recorded with every logging method (except the NGS™ run) to correlate depth runs between each survey conducted.

The Schlumberger logging summary report for BH-1 and the geophysical logs for all Schlumberger methods, compiled as a montage, are presented in Appendix C (on CD inside back cover of this report).

6.0 HYDROGEOLOGY

A preliminary assessment of the hydrogeologic features encountered during drilling operations at BH1 is presented below. Included is a brief description of the geologic units identified during characterization of cuttings. Groundwater occurrences are discussed based on drilling evidence, open-hole video logging, and geophysical logging data. Depths will be slightly different at BH2.

6.1 Stratigraphy and Lithologic Logging

Rock units and stratigraphic contacts were determined primarily from data collected by the visual examination of drill core and cuttings samples and should be considered preliminary. Such interpretations may be revised upon future detailed analysis of petrographic, geochemical, mineralogical, and geophysical logging data by the Laboratory. A lithologic log for BH1 is provided in Appendix D.

Alluvium (0 to 29 ft bgs)

Alluvium was encountered in the interval from ground surface to 29 ft bgs in BH1. Core samples revealed unconsolidated sand and gravel deposits on the floor of Los Alamos Canyon. These Quaternary deposits are made up of tuffaceous silty sands containing subangular dacite cobbles (up to 6 cm) that were likely derived from Tschicoma Formation volcanic flows.

Bandelier Tuff (29 to 93 ft bgs)

The Quaternary Bandelier Tuff in BH1 includes the Otowi Member ash-flow tuff and the underlying Guaje Pumice Bed.

Ash-flows of the Otowi Member of the Bandelier Tuff (29 to 73 ft bgs)

BH1 passed through 44 ft of nonwelded to poorly welded rhyolite ash-flow tuff that represents the basal part of the Otowi Member of the Bandelier Tuff. The unit is generally well altered, brown to yellowish-brown in color, and it contains abundant pumice lapilli, 10% or less quartz and sanidine phenocrysts, and minor volcanic lithic fragments enclosed in a matrix of vitric ash. Vitric pumice lapilli (up to 6 cm) are common, exhibiting a fibrous texture and color ranging from white to yellowish-orange. Xenolith fragments are primarily dacitic in composition. The cored section included strongly altered clay-rich intervals up to 5 ft thick.

Guaje Pumice Bed (73 to 93 ft bgs)

BH1 passed through approximately 20 ft of light tan-colored tuff containing abundant small gray-to-white pumice lapilli with interstitial clay, silt, and sand. This unit is interpreted to represent pumice fall deposits of the Guaje Pumice Bed. Pumice and matrix material in this interval generally exhibit strong alteration to clay. Individual clay-rich intervals exhibited minor groundwater saturation, based on the wetness of core retrieved.

Upper Puye Formation (93 to 180 ft bgs)

The 87-ft-thick cored interval from 93 to 180 ft bgs in BH1 contained brown silt and silty sand, with local small percentages of pebble gravel. These sediments are interpreted to represent a fine-grained facies within the upper part of the Pliocene Puye Formation.

Cerros del Rio Basalt (180 to 362 ft bgs)

BH1 passed through a 182-ft-thick sequence of basalt flows that make up the Pliocene Cerros del Rio basalt. Core recovery was attempted from 180 to 261 ft bgs; however, core recovery was poor. Basalt descriptions below 261 ft bgs are based on drill cuttings.

The upper 81 ft (180–261 ft) of Cerros del Rio Basalt is dark gray, vesicular to massive basalt with local clay-filled fractures. An oxidized scoriaceous zone occurs from 213.5 to 222 ft bgs. Basalt in the interval from 261 to 296 ft bgs is dark gray olivine basalt with an aphanitic groundmass that has few vesicles. Light brownish-gray scoriaceous basalt that is oxidized and exhibits clay-alteration occurs from 296 to 311 ft bgs. Medium light gray, massive basalt with small phenocrysts of olivine and pyroxene in an aphanitic groundmass was encountered from 311 to 316 ft bgs, underlain by a 5-ft-thick layer of oxidized scoria. The basal interval, from 321 to 361 ft bgs, consists of light gray, massive basalt with phenocrysts of olivine (commonly displaying iddingsite alteration), pyroxene, and plagioclase in an aphanitic groundmass. Intercalated massive and scoriaceous basalt intervals suggest that the Cerros del Rio basalt is a sequence of basalt flows separated by inter-flow breccias.

Lower Puye Formation (362 to 1022 ft bgs)

BH1 encountered volcaniclastic siltstones, sandstones, and gravels in the interval from 362 to 1022 ft bgs. These weakly cemented sedimentary deposits represent a lower section of the Puye Formation. The interval from 362 to 552 ft bgs contains volcaniclastic sands and gravels with clasts of hornblende-dacite, silicified dacite, rhyolite, and locally minor pumice. From 552 to 762 ft bgs, the sediments are texturally similar to the upper interval with clasts typically dominated by porphyritic dacite, silicified dacite, and flow-banded rhyolite. However, this subdivision contains a component of Precambrian quartzite and metamorphosed granitic rocks ranging from 5% to 15% by volume. The presence of quartzite suggests a depositional environment that resulted in the local mixing of volcanic-rich Puye alluvial fan deposits with axial gravels of the ancestral Rio Grande. Dethier (1997, 49843) described the Totavi Lentil as a quartzite-rich gravel interlayered within the Puye Formation that contains more than 80% casts of quartzite and other Precambrian crystalline rocks. The relatively small percentage of Precambrian clasts suggests that the quartzite-bearing facies in this Puye interval should not be classified as the Totavi Lentil.

The interval from 762 to 842 ft bgs is made up of fine sand to gravel layers with mixed varieties of volcanic clasts (dacite to basalt) and generally contains only a trace of quartzite clasts. Sediments from 842 to 1002 ft bgs contain mixed volcanic lithologies (hornblende dacite, silicified dacite, rhyolite, basalt) and have a significant component (10% to 30%, or more) of pumice. Pumice casts are generally altered, brown in color, and waxy in appearance.

6.2 Groundwater Occurrences and Characteristics

Because of its location in Los Alamos Canyon and its depth, drilling for characterization well R-8 was expected to encounter both perched groundwater zones and regional aquifer saturation. Minor zones of possible saturation were identified, although none produced sufficient water for sample collection.

Moist core samples were first observed during coring of alluvial sediments that consist of unconsolidated silty sands and gravels from 18.5 to 21.5 ft bgs. Formation moisture was also identified by core within the Otowi Member of the Bandelier Tuff at a depth of 56.5 to 71.5 ft bgs. This zone was characterized by clay-altered rhyolite tuff with some clays exhibiting high plasticity.

A video camera survey in the cored section of BH1 revealed possible saturation within the Guaje Pumice Bed from the depth of 77 to 261 ft bgs. Saturated core intervals in the Guaje Pumice Bed were also noted from 83.4 to 83.6 ft bgs and from 91.5 to 93 ft bgs. Drilling was halted at 95 ft bgs to allow for borehole water accumulation. The quantity of water collected (approximately 40 mL) after 1 hr was insufficient for sampling.

Core drilling continued into the Puye Formation where water was injected into the core hole beginning at approximately 134 ft bgs to facilitate coring advancement. Observation of any naturally saturated perched zones from this point forward was not possible because water was used for coring. Coring continued into the Cerros del Rio basalt to a total cored depth of 261 ft bgs. A video log of the borehole was made (see Appendix B). No standing water was noted in the borehole, although some moisture was observed on the borehole wall.

Fluid-assisted, air-rotary drilling methods were used for the remainder of BH1. Drillers reported the presence of groundwater in the borehole at a depth of 763 ft bgs. Depth to water initially was measured at 687 ft bgs. The water level later stabilized in the borehole at approximately 709 ft bgs, and a water sample was collected for analysis.

7.0 WELL DESIGN AND CONSTRUCTION

Characterization well R-8 was installed in BH2. Sections 7.1 and 7.2, respectively, describe the R-8 well design and construction.

7.1 Well Design

The well design for R-8 was completed jointly by the Laboratory and WGII, in consultation with the US Department of Energy and the New Mexico Environmental Department. Geophysical logs, video logs, borehole geologic samples, water-level data, field water-quality data, and drillers' observations were reviewed by the Groundwater Investigations Team to determine screen placement intervals for the well. The well design for R-8 specified two screens to monitor the distribution and concentration of potential contaminants in the regional aquifer. The number and placement of screens were designed to meet the following criteria:

- to monitor the top of the regional zone of saturation (screen 1) and
- to monitor a deeper, more productive zone within the regional aquifer (screen 2).

Productive intermediate perched groundwater zones were not encountered during drilling, and therefore no screens were placed above the regional aquifer. The planned and actual screen locations are given in Table 7.1-1.

Table 7.1-1
Summary of Well Screen Information for Characterization Well R-8

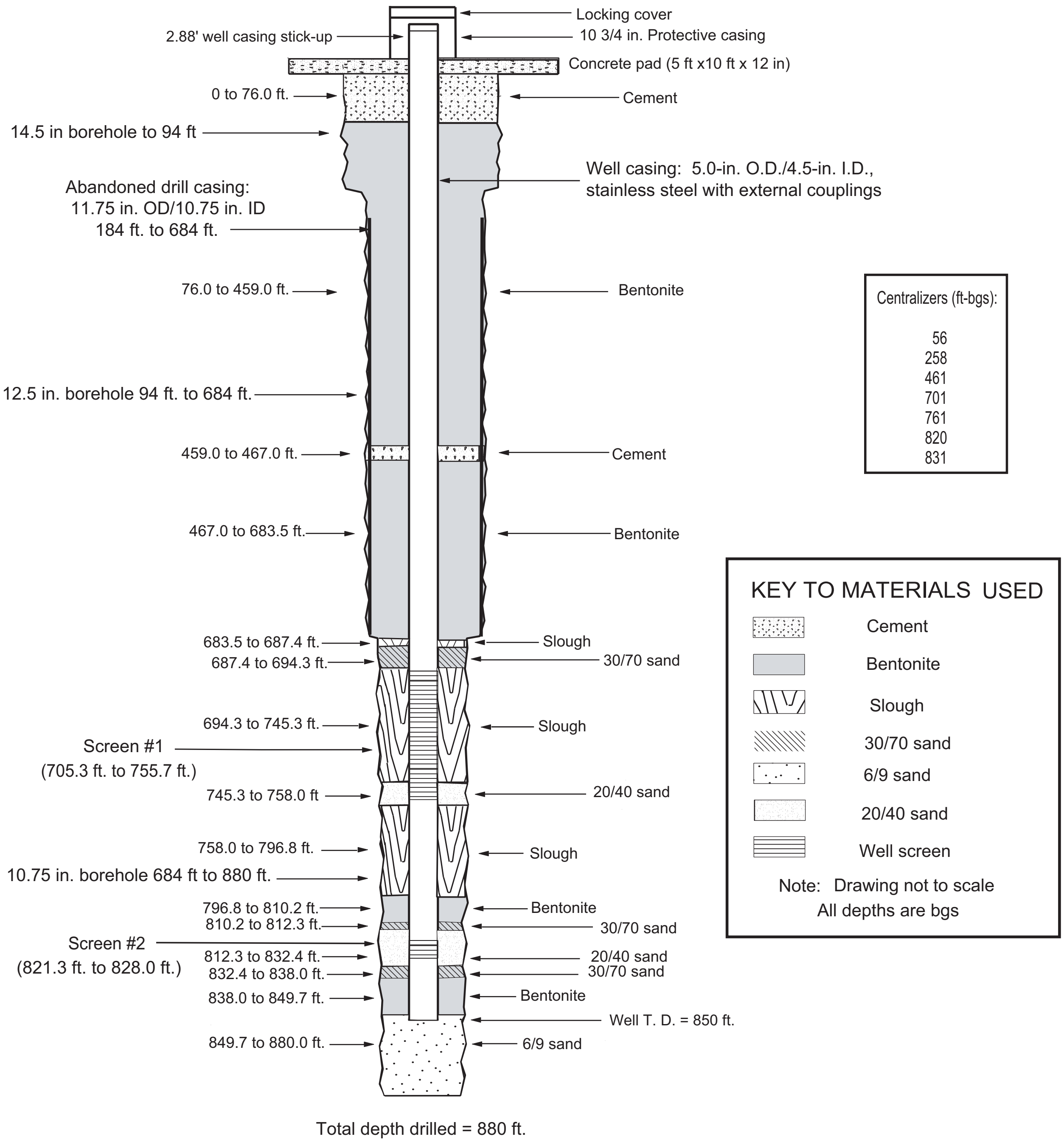
Screen	Planned Depth* (ft)	Actual Depth* (ft)	Geologic/Hydrologic Setting
1	705.4–757.0	705.3–755.7	Top of regional zone of saturation in the Puye Formation
2	821.8–828.6	821.3–828.0	Within the regional zone of saturation in the Puye Formation

*Depths listed above represent the perforated interval of the screens.

7.2 Well Construction

The blank pipe well casing and pipe-based screens were manufactured using 4.5-in. inner diameter (ID)/5.0-in. OD type 304 stainless steel fabricated to American Society for Testing of Materials (ASTM) 1994 A554 standards. The external couplings also were type 304 stainless steel fabricated to ASTM standard A312, which exceed the tensile strength of the threaded casing ends. The pipe-based screens were modified by Weatherford Well Screens (Johnson Screens, Inc.) from 10-ft sections of blank well casing by drilling a series of 0.385-in.-diameter holes and then welding a stainless steel wire-wrap (with 0.010-in. spacing) over the perforated interval. The final OD of the screens was 5.56-in.

The stainless steel well components were cleaned at the well site using a steam cleaner and scrub brushes. The base of the well was set at 850.0 ft bgs. Stainless steel centralizers were installed above and below each screen and in several locations above the zone of regional saturation to stabilize the borehole and centralize the well within the borehole during backfill placement operations (Figure 7.2-1). All annular materials were placed in the borehole/well casing annulus through a tremie pipe.



Notes: 1. The screen intervals list the footages of the pipe perforations, not the top and bottom of screen joints.
2. The formation slough around screen #1 consists of volcaniclastic sands and gravels.
3. Pipe-based screen: 5.56-in. O.D./ 4.5-in. I.D., 304 stainless steel with s.s. wire wrap; 0.010-in slots.

Figure 7.2-1. As-built configuration diagram of characterization well R-8 in BH2

7.2.1 Well Installation

Well installation consisted of connecting joints of stainless steel screens and stainless steel well casing as specified in the well design (Section 7.1). Dynatec installed the well casing on January 27 and 28, 2002. Figure 7.2-1 illustrates the final well casing configuration and indicates the depths of the various well components from ground surface to TD.

7.2.2 Annular Fill Placement

Table 7.2-1 summarizes the annular fill materials installed. The final configuration of the annular materials is also illustrated in Figure 7.2-1.

Table 7.2-1
Annular Fill Materials Used, Characterization Well R-8

Material	Use/Function	Amount	Unit*
20/40 sand (medium-grained)	To pack screen intervals	43	bag
30/70 sand (fine-grained)	To separate filter packs from bentonite seals	20	bag
6/9 sand (coarse)	To bridge formation fractures and matrix pores	52	bag
Benseal® (bentonite)	As a high-solids, multipurpose grout	2	bag
Holeplug® (.375-in. angular and unrefined bentonite chips)	To provide a borehole annular seal	496	bag
Pelplug® bentonite (.25 in. by .375 in., refined elliptical pellets)	To provide a borehole annular seal below the water table	46	bucket
Portland® cement (mixed with municipal water at a ratio of 5 gal. water to 1 bag)	To provide annular support and surface seal on the upper 100 ft of the borehole	70	bag

*Sand bag = 45 lb ea, bentonite bag/bucket = 50 lb ea, cement bag = 94 lb ea.

Annular fill was placed using steel tremie pipes to deliver annular materials at the depth intervals specified in the Title II well design (Figure 7.2.1). The bottom of the borehole was measured with a tag line at 880.1 ft bgs before fill material was introduced into the annulus. Dynatec installed the annular fill material from January 28 through February 1, 2002. Filter packs across screened intervals consisted of silica sand materials mixed with municipal water and placed in the annulus as a fluid slurry, except at screen 1 where natural slough occurred behind most of the screened interval from 694.3 ft bgs to 745.3 ft bgs. Bentonite materials were placed between screened intervals to seal the annular space and prevent interaction between water-bearing zones. Portland cement (mixed at a ratio of 5 gal. of water per bag of cement) was used to provide a seal between the screened section and the upper casing string of the well and to protect the annular space in the upper 76 ft of the borehole. Approximately 5720 gal. of municipal water were used during annular fill material placement.

8.0 WELL DEVELOPMENT AND HYDROGEOLOGIC TESTING

Well development procedures included wire-brushing, screen swabbing and surging, bailing, and pumping. Development activities were followed by hydraulic slug tests conducted across screen 2.

8.1 Well Development

Well development at R-8 was performed in two stages. The initial stage consisted of wire-brushing the well interior, swabbing and surging the screened intervals to draw fine sediment from the constructed filter packs, and bailing to remove solid materials from the well. In the second stage, a submersible pump was lowered to screen 2 and on/off cyclic pumping from the water-bearing zone was performed to remove any remaining fines from the filter pack and surrounding formation.

Criteria for well development were based on selected field water-quality parameters (turbidity, specific conductance, pH, and temperature) measured in groundwater samples. To monitor progress during each development stage, groundwater samples were collected periodically and time-series parameter measurements were recorded. One objective of well development was to remove suspended sediment from the water until turbidity, measured in nephelometric turbidity units (NTU), decreased to a value of less than 5 NTU for three consecutive samples. Similarly, the other measured parameters needed to be stabilized before terminating development procedures. The well was declared developed when the above criteria were met. Table 8.1-1 presents data for water-quality parameters measured at the beginning and end of each well-development method.

Table 8.1-1
Development of Characterization Well R-8

Method	Water Produced (gal.)	Range of Parameters[a]			
		pH	Temperature (°C)	Specific Conductance (µS/cm)[b]	Turbidity (NTU)
Bailing - sumping	350	7.94–7.98	21.7–20.7	315–241	34.7–40.4
Bailing/swabbing sump	2180	7.90–8.11	20.9–18.9	245–217	90.7–39.7
Surging/bailing screens 1 and 2	4470	7.51–7.89	20.6–20.3	214–200	>1000–21.4
Pumping screen 2	12,740	7.72–7.85	16.0–22.8	201–226	59.6–1.39

[a] Parameters presented as value at beginning followed by value at end of development method.
[b] Specific conductance reported in microsiemens per centimeter.

To remove any materials that may have been introduced to the well interior during construction, the casing and screens were first cleaned thoroughly with a wire brush. Preliminary bailing using a 12-gal. steel bailer was performed to remove debris and sediment from the sump. A swabbing tool then was lowered in the well and drawn repeatedly across each of the two screen intervals while municipal water was injected at a rate of 20 gal./min.

Bailing and surging techniques then were applied individually to screens 1 and 2. In surging the well, a wire-line surge block with an attached section of pipe for added weight was used to create rapid upward-downward strokes and to facilitate changing to a wire-line bailer. The surging technique was applied in 5-ft stroke intervals starting at the top and progressing downward through the screened interval. A total of 6720 gal. of water was purged from the well prior to the pump-development stage. Water turbidity exceeded 1000 NTU at the beginning and was reduced to 21.4 NTU at the end of bail-and-surge development (Table 8.1-1).

Pump-development procedures at R-8 were applied to screen 2 (i.e., the screened interval from 821.3 to 828.0 ft bgs) using a 7.5 horsepower (hp) submersible pump. The pump intake was lowered to the bottom of the screen and the pump was cycled on at a nominal rate of 20 gal./min while water samples were collected at regular intervals (hourly) for parameter measurements. The pump was then cycled off for a minimum 15-min period of water-level recovery. About 12,700 gal. were purged from the well during eight pumping cycles. Turbidity levels in collected water samples ranged from 59.6 to 1.39 NTU throughout the pump-development stage (Table 8.1-1).

Figure 8.1-1 illustrates the variation in measured field parameters versus gallons of water purged during pump development of screen 2. The graphed parameters demonstrate that specific conductance, pH, and temperature were stable during the final period of pumping and that turbidity had fallen consistently below 2 NTU when R-8 was declared fully developed.

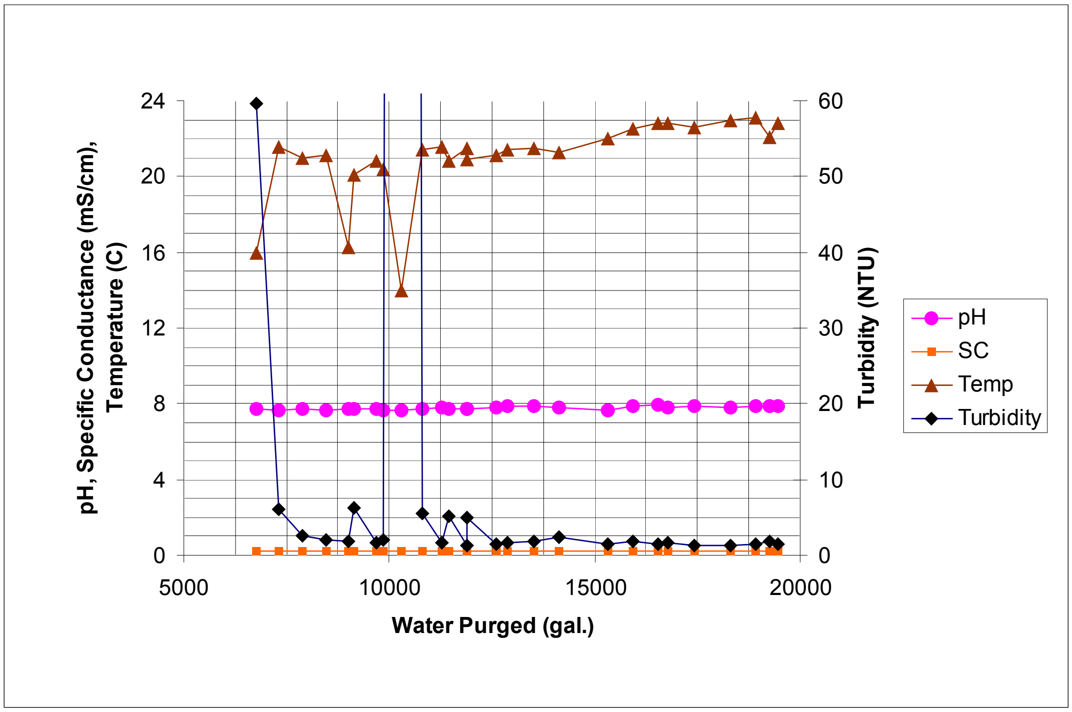


Figure 8.1-1. Effects of pump development on water quality parameters (screen 2)

8.2 Hydrologic Testing

The Laboratory conducted three hydrologic tests at screen 2. A packer assembly consisting of two inflatable packers, one above and one below the screen, was temporarily installed along with an electronic pressure transducer to measure water levels as the test proceeded. A slug of municipal water was injected between the packers and the variation in water-level depth was recorded continuously as the introduced water was absorbed by the aquifer. Preliminary results indicated that the water-bearing zone of screen 2 has a production capacity exceeding 23.8 gal./min. Because the level of the regional water table occurred below the top of screen 1, conducting slug tests in the upper screen of well R-8 was not appropriate. Hydrologic testing, methodologies, results, and data evaluations will be presented in a separate report.

Approximately 450 gal. of municipal water were pumped into well R-8 during the three slug tests. Following the tests, additional bailing was performed to remove all injected test water. A total of 2250 gal. was bailed from the well to complete all development and hydrologic testing activities.

8.3 Installation of Westbay™ Monitoring System

A Westbay™ sampling system was installed inside the stainless steel well casing after development and testing procedures in well R-8 were completed. The base of the multiport casing was set at 847.5 ft bgs. The system is set in place using a series of packers inflated with de-ionized water and positioned to target each well screen with a set of valved ports. The R-8 system contains four ports used to inflate the packers and test six packers. Screen 1 is accessed by four measurement ports, and screen 2 is accessed by two measurement ports. Both measurement zones also contain a pumping port. Quarterly sampling of Westbay™-equipped wells is accomplished using a Laboratory-owned sampling trailer outfitted with the MOSDAX sampling system (controller, sampler probe, and sample bottle train) and a motorized winch-and-boom system. The Westbay™ summary MP casing log provides details of the installed system (Appendix E).

9.0 WELLHEAD COMPLETION AND SITE RESTORATION

When operational tests were completed on the installed sampling system, the protective casing height was adjusted to accommodate a locking cap over the Westbay™ installation. Finish work commenced on the wellhead area, well components were surveyed, and the site underwent final cleanup and restoration.

9.1 Wellhead Completion

Surface completion for well R-8 involved constructing a reinforced (3000 psi) concrete pad, 5 ft by 10 ft by 12-in.-thick, around the well casing to ensure long-term structural integrity of the wellhead (Figure 9.1-1). The concrete pad was emplaced on April 17, 2002. A brass survey pin was installed in the northwest corner of the concrete pad. A 3-in. threaded galvanized-steel conduit, approximately 18 in. long with a 12-in. stickup, was embedded vertically through the pad to allow future installation of a solar-powered energy supply. A 10.75-in. steel protective casing with locking lid protects the well riser. Four 4-in.-diameter steel bollards were placed adjacent to each side of the pad. The bollard next to the west side of the pad can be removed to facilitate access to the well for sampling and maintenance. The pad was designed to be slightly elevated with base-course graded up around the pad to promote drainage.

9.2 Geodetic Survey

A Southwest Mountain Surveys, Inc. (NMPLS #6998) conducted a geodetic survey of well R-8 and BH1 on April 22, 2002, using a Topcon GTS B-3, 3 Second Theodolite total stations. Controls for the survey were Brass Cap A-006 (Airport) and Pajarito Tower from the 1992 Laboratory-wide control network. Field measurements were reduced using Terra Model software. Table 9.2-1 summarizes the results of readings conducted for various components of the completed wellhead.

The survey at R-8 located the brass cap monument in the northwest corner of the concrete pad and also measured elevations to the top of the protective casing, the top of the Westbay™ casing, and the top of the Westbay ™ plate (Table 9.2-1). The survey also located the brass cap monument on top of the concrete plug at abandoned borehole BH1. Horizontal well coordinates are New Mexico State Plane Grid Coordinates, Central Zone (North American Datum, 1983 [NAD 83]), and are expressed in feet. Elevation is expressed in feet above mean sea level relative to the National Geodetic Vertical Datum of 1929.

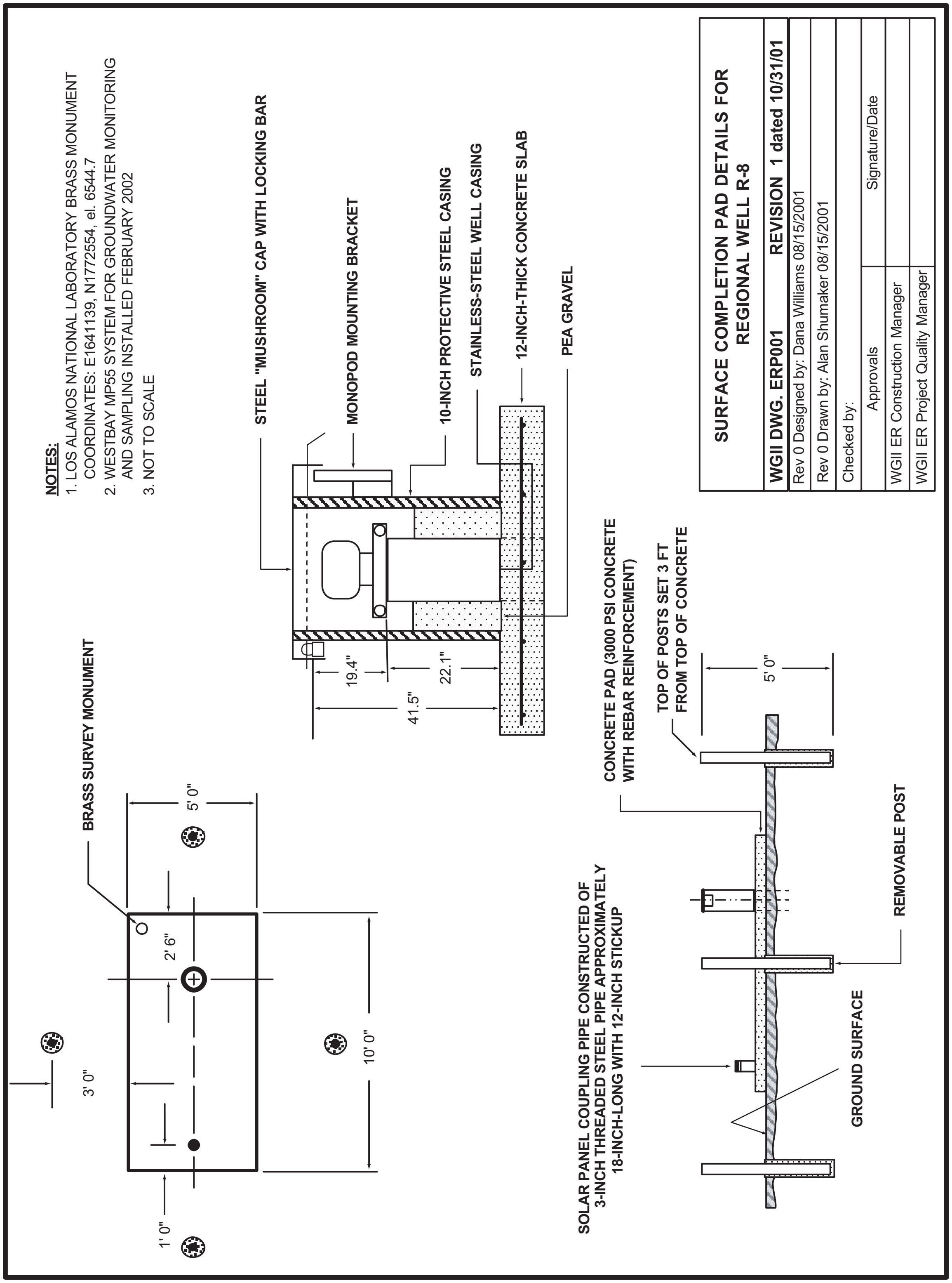


Figure 9.1-1. Surface completion configuration diagram

Table 9.2-1
Geodetic Data for Characterization Well R-8 and BH1

Description	East	North	Elevation
Brass cap in R-8 pad	1641139.01	1772554.62	6544.74
Top of protective casing	1641139.65	1772553.18	6547.61
Top of Westbay™ casing	1641139.71	1772552.75	6547.45
Top of Westbay™ plate	1641139.17	1772552.94	6547.29
Brass cap in BH1 plug	1641195.51	1772533.44	6542.89

The Facility for Information Management, Analysis and Display (FIMAD) location identification number for the R-8 well and BH1 is 72-10000.

9.3 Site Restoration

From April 8 to 18, 2002, drilling site restoration activities were conducted by S. G. Western Construction Company. Waste-management activities were conducted before and concurrent with restoration. Waste materials were removed from the site as specified by the WCSF.

Drilling activity waste streams included drilling fluids, cuttings, and development water, which were sampled for contaminant analysis. The test data then were reviewed by the New Mexico Environment Department (NMED) and the Laboratory, and the waste was approved for on-site disposal. The drill cuttings were used to help backfill the containment area, and drilling fluids and development water were applied adjacent to the site with a 3-in. pipe irrigation system.

The cuttings-containment area was excavated and the plastic lining was removed. The containment basin then was backfilled with dirt that had been bermed during pad construction and regraded. Base-course gravel also was regraded and compacted across the site to form a smaller pad. The site was reseeded with a blend of native grasses mixed with fertilizer and mulch to facilitate regrowth of ground cover.

10.0 DEVIATIONS FROM THE R-8 FIP

Appendix A compares the characterization activities that were performed at R-8 with the planned activities described in the hydrogeologic work plan (LANL 1998, 59599) and the R-8 FIP (LANL 2001, 71282.1). Significant deviations are discussed below.

- Planned Depth. The R-8 FIP states that the planned depth of R-8 would be approximately 1200 ft bgs. The first borehole was advanced to a depth of 1022 ft bgs; as a result of problems at shallower depths and the subsequent loss of tools in the hole, the boring was abandoned. Because of the information obtained from the first boring, a second boring was advanced to a depth of 880 ft bgs for well installation only.
- Number of water samples collected for contaminant analysis. The R-8 FIP states that up to three borehole groundwater samples would be collected to target groundwater in the perched zones and the regional aquifer. One water sample was collected from the regional aquifer at 822 ft bgs. Several moist intervals were encountered during BH1 coring operations; however, these intervals did not produce sufficient amounts of water to collect samples. Once tools became stuck and

fishing operations began, there were no opportunities to collect water samples from the regional aquifer.

- Filter material. In all installations, a 20/40 silica sand filter pack is placed opposite the screened intervals, and an attempt was made to place 10 ft of material above the top of the screen and 5 ft below. However, during backfill placement of screen 1, the Puye Formation caved into the hole as the 9.625-in. drill casing was retracted. Therefore, a natural filter pack is opposite a portion of screen 1 from 745.3 to 694.3 and extends 11 ft above the top of the screen.

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Southwest Mountain Surveys provided the final geodetic survey of finished well components.

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Washington Group International, Inc., helped to prepare portions of this report.

R. Bohn of Los Alamos National Laboratory reviewed this report for classification purposes.

P. Prado and E. Louderbough, Los Alamos National Laboratory legal counsel, reviewed this report for legal purposes

D. Broxton, P. Longmire, S. Pearson, W. Stone, and D. Vaniman of Los Alamos National Laboratory, prepared this report.

12.0 REFERENCES

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LANL (Los Alamos National Laboratory), May 22, 1988. "Hydrogeologic Workplan," Los Alamos, New Mexico. (LANL 1988, 59599)

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Appendix A

Activities Planned for R-8 Compared with Work Performed

Activity	Hydrogeologic Work Plan	R-8 Field Implementation Plan	BH1 Actual Work	BH2 /R-8 Actual Work
Planned Depth	100 to 500 ft into the regional aquifer	Approximately 1200 ft bgs	Total drill depth 1022 ft bgs	Total drill depth 880 ft bgs
Drilling Method	Methods may include, but are not limited to, hollow-stem auger (HSA), air-rotary/Odex/Stratex, air-rotary/Barber rig, and mud-rotary drilling	HSA, casing-advance, open-hole , and fluid-assisted, air-rotary equipment	Air-rotary core with wire-line retrieval and fluid-assist air rotary RC with casing-advance	Fluid-assist air rotary RC with casing-advance
Amount of Core	10% of the borehole	Continuous core to refusal	Core from 0 to 261 ft bgs	No core attempted
Lithologic Log	Log to be prepared from core, cuttings, and drilling performance	Log to be prepared from core, cuttings, geophysical logs, and drilling performance	Log from core, cuttings, geophysical logs, and drilling performance	No log produced from BH2
Number of Water Samples Collected for Contaminant Analysis	A water sample may be collected from each saturated zone, five zones assumed. The number of sampling events after well completion is not specified.	Up to three borehole groundwater screening samples will be collected for geochemical and contaminant characterization during drilling. These samples will target groundwater in the perched zones and in the regional aquifer.	One water sample was collected from the regional aquifer at 822 ft bgs	No water samples obtained
Water Sample Analysis	Initial sampling: Radiochemistry I, II, and III, tritium, general inorganics, stable isotopes, volatile organic compounds (VOCs), and metals. Saturated zones: radionuclides (tritium, ^{90}Sr, ^{138}Cs, ^{241}Am, plutonium isotopes, uranium isotopes, gamma spectrometry, and gross alpha, beta, and gamma), stable isotopes (hydrogen, oxygen, and in special cases nitrogen), major ions (cations and anions), trace metals, and trace elements.	Metals (dissolved), Anions (dissolved), gamma spectrometry, ^{241}Am, ^{137}Cs, ^{238}Pu, $^{239,240}Pu$, ^{234}U, ^{235}U, ^{238}U, ^{90}Sr (total), Stable Isotopes: $^{18}O/^{16}O$, D/H, $^{15}N/^{14}N$, tritium, tritium (low level or direct counting), RV Gross-alpha, beta plus RV Gross-gamma, TUICPMS, TKN, CLO_4^-	Moisture content, anions, O and N stable isotopes, radionuclides, tritium, metals, and low-level rad screening	Samples will be collected during quarterly sampling.
Water Sample Field Measurements	Alkalinity, pH, specific conductance, temperature, turbidity	pH, specific conductance, temperature, turbidity	Parameters measured: pH, specific conductance, temperature, turbidity	Parameters measured during development: pH, specific conductance,

Activity	Hydrogeologic Work Plan	R-8 Field Implementation Plan	BH1 Actual Work	BH2 /R-8 Actual Work
				temperature, turbidity
Number of Core/Cuttings Samples Collected for Contaminant Analysis	Twenty samples of core or cuttings to be analyzed for potential contaminant identification in each borehole.	Core samples will be collected every 5 ft during drilling by HSA from the surface to the base of the Bandelier Tuff. For the Puye Formation and Cerros del Rio lavas, a mechanical sidewall-coring tool will be used to collect sidewall cores at 10 ft intervals down to the depth of the regional aquifer. Up to 5 core/cuttings samples will be collected within water-bearing zones encountered during drilling.	156 core samples and 6 cuttings submitted for analysis	No core or cuttings samples collected
Core Sample Analytes	Uppermost sample to be analyzed for a full range of compounds: deeper samples will be analyzed for the presence of radiochemistry I, II, and III analytes, tritium (low-and high-detection levels), and metals. Four samples to be analyzed for VOCs.	Core samples will be analyzed for boron, bromide, chloride, fluoride, nitrate, nitrite, oxalate, sulfate, perchlorate, TKN, $^{18/16}O$, D/H, $^{15}N/^{14}N$, tritium, ^{241}Am, ^{238}Pu, $^{239,240}Pu$, ^{234}U, ^{235}U, ^{238}U, ^{90}Sr, Gross alpha, Gross beta, Gross gamma	Core samples will be analyzed for boron, bromide, chloride, fluoride, nitrate, nitrite, oxalate, sulfate, perchlorate, TKN, $^{18/16}O$, D/H, $^{15}N/^{14}N$, tritium, ^{241}Am, ^{238}Pu, $^{239,240}Pu$, ^{234}U, ^{235}U, ^{238}U, ^{90}Sr, Gross alpha, Gross beta, Gross gamma	No core obtained
Laboratory Hydraulic-Property Tests	Physical properties analyses will be conducted on 5 core samples and will typically include moisture content, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics.	No laboratory hydraulic property tests planned	No laboratory hydraulic property tests performed	No samples collected
Geology	Ten samples of core or cuttings will be collected for petrographic, X-ray fluorescence (XRF) and X-ray diffraction (XRD) analyses	Analytical testing of samples may include mineralogy by XRD, petrography by modal analysis of thin sections, analysis by electron microprobe or scanning electron	Eleven samples were collected for mineralogic, petrographic, and geochemical analysis and characterization.	No samples collected

Activity	Hydrogeologic Work Plan	R-8 Field Implementation Plan	BH1 Actual Work	BH2 /R-8 Actual Work
		microscope, and geochemistry by XRF		
Geophysics	In general, open-hole geophysics includes caliper, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape (axial and side scan), fluid temperature (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes: gamma-gamma density, natural gamma, and thermal neutron.	In general, open-hole geophysics includes caliper, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape, fluid temperature (saturated), fluid resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes gamma-gamma density, natural gamma, and thermal neutron.	LANL tools: Video: 30–261 ft bgs, natural gamma: 0–261 ft bgs, and 0–768 ft bgs, induction: 30–261 ft bgs; Schlumberger geophysics: 0–761 ft bgs (cased), 761–764 ft bgs (open-hole): Lithodensity, spectral gamma, elemental capture, thermal/epithermal neutron, natural gamma.	No geophysics performed
Water-Level Measurements	Procedures and methods not specified in Hydrogeologic Workplan.	Static water level shall be measured by the field team leader using a dedicated water level meter and/or pressure transducer system set with a water-level tape.	Water-level measurements were obtained during drilling using a water-level meter.	Water-level measurements were obtained during drilling using a water-level meter.
Field Hydraulic-Property Tests	Not specified in hydrogeologic work plan	Slug or pumping tests may be conducted in saturated intervals once the well is completed	None conducted	Falling head test on R-8 screen 2
Surface Casing	Approximately 20-in. outer diameter (OD), extends from land surface to 10-ft depth in underlying competent layer and grouted in place.	18-in. OD steel casing will be installed and cemented in place to isolate the borehole and to stabilize the upper part of the borehole from caving and collapse (no specific depth given).	18-in. OD steel casing set at 30 ft	No surface casing utilized
Well Casing	6.625-in. OD	5-in. OD x 4.5-in. ID	No well was installed.	5-in. OD (4.5-in. ID) stainless steel casing w/ external couplings

Activity	Hydrogeologic Work Plan	R-8 Field Implementation Plan	BH1 Actual Work	BH2 /R-8 Actual Work
Well Screen	Machine-slotted (0.01-in.) stainless steel screens with flush-jointed threads; number and length of screens to be determined on a site-specific basis and proposed to NMED.	Well screen shall be constructed with multiple sections of 5.56-in OD (4.5-in. ID) pipe based, stainless steel, wire wrapped, 0.010-in. slotted screen	No well was installed.	Screened intervals constructed of 5.56-in OD (4.5-in. ID) pipe-based, stainless steel, wire -wrapped, 0.010-in. slotted screen.
Filter Material	>90% silica sand properly sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen.	Primary filter pack shall consist of round, clean, washed and resieved silica sand with a uniformity coefficient of 2.0 or less, placed a minimum of 10 ft above and 5 ft below the well screen. The size of the filter pack shall be selected based on the characteristics of the formation to be screened. Secondary filter pack is finer, clean, washed (30/70, 20/40) or other appropriate silica sand sizes shall be placed a minimum of 2 ft below and above the primary pack.	No well was installed.	Primary filter pack: 20/40 silica sand placed 4.4 ft below and 9 ft above screen 2. Secondary filter pack: 30/70 silica sand placed in a layer 5.6 ft-thick below and 2.1 ft-thick above. Primary filter pack: 20/40 silica sand placed 2.3 ft below and 10 ft into screen 1, slough to 11 ft above the screen. Secondary filter pack: 30/70 silica sand in a 7-ft-thick layer above screen.
Conductor Casing	Carbon-steel casing from land surface to top of stainless steel casing.	Carbon-steel casing 5.56-in. in diameter extending from land surface to dielectric coupling at top of stainless steel casing	No well was installed	Carbon-steel casing from land surface to top of stainless steel casing
Backfill Material (exclusive of filter materials)	Uncontaminated drill cuttings below sump and bentonite above sump.	The annular space in the blank zones between filter packs associated with screens (for a multiscreen well) and above the top-most secondary filter pack of a single-completion well shall be sealed with a mixture of approximately 50% bentonite (chips or pellets) and 50% gravel or sand. As necessary, 5 to 10 ft cement plugs may be	No well was installed.	6/9 sand in borehole below well casing; bentonite seal below filter pack; bentonite and slough between filter packs, and bentonite above screens. One cement grout plug from 459 to 467 ft bgs and cement from surface to 76 ft bgs.

Activity	Hydrogeologic Work Plan	R-8 Field Implementation Plan	BH1 Actual Work	BH2 /R-8 Actual Work
		placed within the bentonite and gravel/sand intervals. The annular space from a depth of approximately 75 ft to land surface shall be sealed with cement grout.		
Sump	Stainless steel casing with an end cap.	5-in. diameter stainless-steel casing 30 ft long with end cap	No well was installed.	Thirty ft sump
Bottom Seal	Bentonite	The interval from total depth to approximately 10 ft below the well screen may be filled with gravel, silica sand, bentonite and/or cement.	No well was installed.	6/9 sand and bentonite

* The Task/Site Work Plan for Operable Unit 1049 Los Alamos Canyon and Pueblo Canyon, November 1995, includes only plans for intermediate-depth borehole and well installation and is therefore not included in Table A-1.01.

Appendix B

LANL Video Borehole Logs
(CD attached to inside back cover)

Appendix C

Schlumberger Geophysical Report/Montage
(CD attached to inside back cover)

Appendix D

Lithology Log

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qal, alluvium	Unconsolidated sediments, silty sand (SM), dark grayish-brown (5YR 6/4), medium to fine sand with minor gravel, pumice fragments common, dry. Note: core samples were collected and are described in the interval from 0 to 261 ft bgs. Replicate drill cuttings were also collected over this same interval and were used primarily for reference in selected intervals of poor, or no, core recovery.	0–8	6544.7–6536.7
	Unconsolidated sediments, silty sand (SM), light brown (5YR 6/4), silt to medium sand, well graded, subrounded gravel clasts consist of locally oxidized pumice.	8–11.5	6536.7–6533.2
	Unconsolidated sediments, silty sand (SM), light brown (5YR 6/4), silt to medium sand, well-graded, local subrounded to subangular gravel clasts. Lithology similar to interval 8 –11.5 ft; gravel clasts more angular.	11.5–14.5	6533.2–6530.2
	No core recovery. Cuttings indicate variety of coarse-crystalline dacites, partly quartz-bearing; <5% tuff detritus.	14.5–18.5	6530.2–6526.2
	Unconsolidated sediments, silty gravel (GM), medium brown (5YR 4/2), cobbles up to 5 cm are subrounded and consist dominantly of dacitic volcanic rocks. Interval 18.5 – 21 ft wet to saturated.	18.5–21.5	6526.2–6523.2
	Unconsolidated sediments, gravel (GW) with sand and silt, moderate brown (5YR 4/2), cobbles (up to 9 cm) with sand and silt matrix; clasts consist mainly of gray dacite porphyry. Interval 22.8 – 23.3 ft bgs is moist.	21.5–28	6523.2–6516.7
	Unconsolidated sediments, silty sand (SM) with gravel, light brown (5YR 6/4), clasts consist of indurated volcanic tuff and dacitic lithic fragments that generally exhibit strong weathering; moist interval. Contact with underlying Bandelier Tuff estimated at 29 ft bgs.	28–30	6516.7–6514.7
Qbo Otowi Member of the Bandelier Tuff	Rhyolite tuff, dark yellowish-orange (10YR 6/6), vitric, nonwelded to slightly welded. Composed of quartz+sanidine phenocrysts (10%) and dacitic lithic fragments in a glassy ash matrix; large fibrous yellow-orange pumices common, moist. Moderate clay alteration at 33.0–37.5 ft bgs and 40.1–45.4 ft bgs. Note: this interval is possibly a detached block of altered tuff.	30–44	6514.7–6500.7
	Rhyolite tuff, clay altered, moderate brown (5YR 4/4). Clay is of high plasticity, fissile, slightly consolidated, wet. Note: steep angular contact with underlying volcanic tuff.	44–45.5	6500.7–6499.2
	Rhyolite tuff, grayish-orange (10YR 7/4), pumice-rich, slightly welded. Composed of quartz+sanidine phenocrysts (8%–10%), dacitic lithic fragments, and fibrous pumices; moist. Note: possible large detached block of tuff.	45.5–56.5	6499.2–6488.2
	Rhyolite tuff, moderate yellowish-brown (10YR 5/4). Tuff is altered, composed of quartz+sanidine crystals, relict pumices and lithic fragments in a matrix of clayey ash. Clay, particularly in the interval 56.5 – 64.5 ft bgs, is of a high plasticity, locally sandy, unconsolidated to weakly indurated, and is wet to saturated.	56.5–71.5	6488.2–6473.2

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qbo Otowi Member of the Bandelier Tuff	Rhyolite tuff, light brown to tan (5YR 6/4), generally silty sand textured altered tuff with white altered tuff fragments and volcanic lithics. Estimated contact with underlying Guaje Pumice Bed at 73 ft bgs.	71.5–73	6473.2–6471.7
Qbog Guaje Pumice Bed	Tephra deposit, light brown to tan (5YR 6/4), generally silty to clayey sand (i.e., altered tuff); lower 5 ft of this interval becoming more clay rich; moist.	73–81.5	6471.7–6463.2
	Tephra deposit, tan (5YR 6/4), composed of soft white pumice fragments and minor lithics in a matrix of fine sand, silt and clay. Note interval 83.4 – 83.6 ft bgs is very soft and wet.	81.5–86.5	6463.2–6458.2
	Tephra deposit, tan (5YR 6/4), altered tuff composed of white pumice fragments with interstitial altered ash, moist, soft.	86.5–87.8	6458.2–6456.9
	Tephra deposit, light brown (5YR 6/4), silt with trace of fine sand; moist.	87.8–90	6456.9–6454.7
	Tephra deposit, reddish-brown (10YR 6/6), altered, composed of gray pumice fragments and minor lithics in a matrix of silt and fine sand; wet to saturated. Note: contact with underlying Puye Formation estimated at 93.0 ft bgs.	90–93	6454.7–6451.7
Tpf Puye Formation	Clastic sediments, light brown (5YR 6/4), altered, consisting mainly of brown silt with fine sand, slightly moist. Interval includes nonwelded biotite-bearing pumices.	93–100	6451.7–6444.7
	Clastic sediments, light brown (5YR 6/4), altered, consisting mainly of brown silt with fine sand, slightly moist.	100–102.5	6444.7–6442.2
	Clastic sediments, silt (ML), reddish-brown (10YR 5/4), silt with fine to coarse sand, trace gravel, moist.	102.5–107.5	6442.2–6437.2
	Clastic sediments, silt (ML), reddish- brown (10YR 5/4).	107.5–126.5	6437.2–6418.2
	Clastic sediments, silty sand (SM) with gravel, reddish-brown (10YR 5/4), 20% silt, 5% pebble-size gravel, 70%–80% sand, subangular to subrounded; slightly moist.	126.5–131.5	6418.2–6413.2
	No sample recovery.	131.5–133	6413.2–6411.7
	Clastic sediments, silty sand (SM) with gravel, reddish-brown (10YR 5/4); similar to interval 126.5 – 131.5 ft; slightly moist.	133–134	6411.7–6410.7
	Clastic sediments, silty sand (SM) with gravel, reddish-brown (10YR 5/4), 20%–30% fines, 70%–80% fine to coarse sand, slightly moist.	134–141	6410.7–6403.7
	Clastic sediments, silty sand (SM) with gravel, reddish-brown (10YR 5/4), 20%–30% fines, 70%–80% fine to coarse sand, minor subangular to subrounded gravel (up to 1 cm), slightly moist.	141–145	6403.7–6399.7
	Clastic sediments, silt (ML), reddish-brown (10YR 5/4), 80%–90% fines, minor fine sand and gravel, moist.	145–147.5	6399.7–6397.2
	Clastic sediments, silty sand (SM), reddish-brown (10YR 5/4), silt with fine sand, local clayey layers up to 5 cm thick, moist, friable.	147.5–152.5	6397.2–6392.2
	Clastic sediments, silt (ML), reddish-brown (10YR 5/4), silt with trace fine subrounded gravel, slightly moist.	152.5–157	6392.2–6387.7

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf Puye Formation	Clastic sediments, silty sand (SM), brown (10YR 5/4), silt with fine sand, silty clay layer in the interval 159–159.5 ft bgs, slightly moist. Lower 5 ft of this interval has weakly cemented layers.	157–172	6387.7–6372.7
	Clastic sediments, silty sand (SM), light grayish-brown (5YR 6/1), fine sand and silt, dry; local layers up to 1.5 cm thick are weakly cemented.	172–174	6372.7–6370.7
	Clastic sediments. Minor percentage (10%) of core recovered in this interval. Sample contains 2.5- to 4-cm fragments of dark gray (N3) vesicular basalt with white amorphous infillings. Note: contact with underlying Cerros del Rio Basalt estimated at 180 ft bgs.	174–177	6370.7–6367.7
Tb Cerros del Rio Basalt	No core recovered at 177 to 184.5 ft bgs. Cuttings from this interval indicate basalt, dark gray (N3), vesicular (up to 50% vesicles), porphyritic, with generally unaltered olivine phenocrysts.	177–184.5	6367.7–6360.2
	Poor (20%) core recovery. Cuttings indicate basalt, dark gray (N3), few vesicles, porphyritic; olivines variably preserved.	184.5–186	6360.2–6358.7
	Basalt, dark gray (N3), vesicular, porphyritic; olivines (3%–4% volume) are unaltered.	186–187	6358.7–6357.7
	Basalt, dark gray (N3), vesicular, porphyritic; olivines (3%–6% volume, up to 1 mm) are unaltered.	187–191	6357.7–6353.7
	Basalt, dark gray (N3 few vesicles, porphyritic; olivines, phenocrysts (up to 1 mm) are unaltered; vesicles partly in-filled with clay.	191–196	6353.7–6348.7
	No core recovered. Cuttings indicate basalt, dark gray (N3), few vesicles vesicular, porphyritic; olivine phenocrysts make up 3%–4% by volume.	196–196.5	6348.7–6348.2
	Basalt, dark gray (N3), few vesicles, porphyritic; olivine phenocrysts (3%–4% volume); core strongly fractured, local fracture surfaces are clay coated.	196.5–197	6348.2–6347.7
	Basalt, dark gray (N3), few vesicles, porphyritic; olivine phenocrysts make up 3%–4% volume; similar to 196.5–197 ft.	197–201	6347.7–6343.7
	No core recovery. Cuttings indicate basalt, dark gray (N3), vesicular, porphyritic; olivine phenocrysts make up 3%–4% by volume.	201–206	6343.7–6338.7
	No core recovery. Cuttings indicate basalt, dark gray (N3), vesicular, porphyritic; olivine phenocrysts make up 5% by volume.	206–207.5	6338.7–6337.2
	No core recovery. Cuttings indicate basalt, dark gray (N3), vesicular, porphyritic; olivine phenocrysts make up 5% by volume.	207.5–208.5	6337.2–6336.2
	Basalt, dark gray (N3), vesicular, porphyritic; olivine phenocrysts make up 5% by volume; several 2–3 cm wide fracture zones with clay and carbonate coating fracture surfaces.	208.5–213.5	6336.2–6331.2

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tb Cerros del Rio Basalt	Basalt, dark gray (N3), vesicular to scoriaceous, porphyritic; minor clay and carbonate coating fractures and filling vesicles.	213.5–217	6331.2–6327.7
	Basalt, dark gray (N3), vesicular to scoriaceous, porphyritic; minor carbonate and clay in vesicles and coating fracture surfaces.	217–222	6327.7–6322.7
	Basalt, medium gray (N5), vesicular, porphyritic; olivine phenocrysts make up 5%–8% by volume;	222–227	6322.7–6317.7
	Basalt, dark gray (N3), vesicular, porphyritic; two fracture zones 10–15 cm thick with clay coating fractures and filling vesicles.	227–232	6317.7–6312.7
	Basalt, dark gray (N3), vesicular, porphyritic; olivine phenocrysts (3%–4% by volume) mostly altered to iddingsite.	232–237	6312.7–6307.7
	Basalt, dark gray (N3), strongly vesicular, porphyritic; olivine phenocrysts (3%–4% by volume) unaltered; silt/clay in-filling of vesicles. Core sample contains subangular cobbles, 3–5 cm.	237–239	6307.7–6305.7
	Basalt, dark gray (N3), few vesicles, porphyritic. Core sample contains subrounded fragments/ cobbles, 2 to 4 cm.	239–243	6305.7–6301.7
	Basalt, dark gray (N3), vesicular, porphyritic; vesicles make up at least 10% by volume.	243–247	6301.7–6297.7
	Basalt, dark gray (N3). Core sample finely ground, vesicularity unknown.	247–248	6297.7–6296.7
	Basalt, dark gray (N3), vesicular, porphyritic; olivine phenocrysts 3%–5% by volume; vesicles make up 10%–20% by volume, rarely in-filled with silt. Note: end of core samples at 261 ft bgs.	248–261	6296.7–6283.7
	Basalt, dark gray (N3), porphyritic with aphanitic groundmass, vesicular. Olivine phenocrysts make up 5% by volume; vesicles make up 10% by volume. Note: drill cuttings are described in the interval from 261 to 1022 ft (TD).	261–266	6283.7–6278.7
	Basalt, dark gray (N3), porphyritic with aphanitic groundmass, vesicular. Olivine phenocrysts (3%–4% by volume) display partial iddingsite replacement; small vesicles make up 5% volume.	266–271	6278.7–6273.7
	Basalt, dark gray (N3), porphyritic with aphanitic groundmass, few vesicles. Olivine phenocrysts (up to 2 mm) make up 5% by volume; rare vesicles lined with clay.	271–276	6273.7–6268.7
	Basalt, dark gray (N3), porphyritic with aphanitic groundmass, few vesicles. Very similar to interval 271–276 ft.	276–281	6268.7–6263.7
	Basalt, medium dark gray (N4), porphyritic with aphanitic groundmass, massive to very few vesicles. Fresh olivine and pyroxene phenocrysts (up to 1 mm) make up 5% by volume; vesicles lined with clay are rare.	281–286	6263.7–6258.7
	Basalt, medium dark gray (N4), porphyritic with aphanitic groundmass, massive to few vesicles; very similar to interval 281–286 ft.	286–291	6258.7–6253.7

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tb Cerros del Rio Basalt	Basalt, medium dark gray (N4), porphyritic with aphanitic groundmass, massive to few vesicles. Olivine phenocrysts (6%–7% by volume) are unaltered.	291–296	6253.7–6248.7
	Basalt, light brownish-gray (5YR 6/1), porphyritic with aphanitic groundmass, few vesicles. Olivine phenocrysts (6%–7% by volume) are generally fresh; clay coating on fragments.	296–301	6248.7–6243.7
	Basalt, dark gray (N3), porphyritic with aphanitic groundmass, vesicular. Olivine and pyroxene phenocrysts; vesicles (25% of volume) commonly in-filled with light brownish gray (5YR 6/1) clay.	301–306	6243.7–6238.7
	Basalt, medium light gray (N5), porphyritic with aphanitic groundmass, vesicular. Olivine and pyroxene phenocrysts (3%–4% volume); vesicles (30% of volume) commonly in–filled with clay.	306–311	6238.7–6233.7
	Basalt, light brownish-gray (5YR 6/1), porphyritic with aphanitic groundmass, few vesicles. Olivine phenocrysts (6%by volume); vesicles (20% of volume) partly in-filled with clay.	311–316	6233.7–6228.7
	Basalt, medium light gray (N6), porphyritic with aphanitic groundmass, vesicular. Olivine and pyroxene phenocrysts (5% by volume); vesicles (20% of volume) partly in-filled with clay.	316–321	6228.7–6223.7
	Basalt, pale yellowish-brown (10YR 6/2), porphyritic with aphanitic groundmass, vesicular to scoriaceous. Vesicles (20% of volume) partly in-filled with clay; local Fe-oxide staining.	321–326	6223.7–6218.7
	Basalt, medium light gray (N6), porphyritic with aphanitic groundmass, few vesicles. Vesicles (20% of volume) partly in-filled with clay.	326–331	6218.7–6213.7
	Basalt, light gray (N7), porphyritic with aphanitic groundmass, vesicular; vesicles make up 15% of volume.	331–336	6213.7–6208.7
	Basalt, light gray (N7), porphyritic with aphanitic groundmass, massive to few vesicles. Olivine phenocrysts (3%–4% by volume) partly rimmed by iddingsite; vesicles make up 5% of volume.	336–346	6208.7–6198.7
	Basalt, light gray (N7), porphyritic with aphanitic groundmass, massive. +10F: (i.e., sample fraction retained on No. 10 sieve) coarse sample chips (up to 3 cm), olivine, pyroxene, and plagioclase phenocrysts (6% volume); olivine phenocrysts up to 2 mm.	346–356	6198.7–6188.7
	Basalt, light gray (N7), porphyritic with microcrystalline groundmass, massive to few vesicles. Olivine phenocrysts (up to 2 mm) make up 6% by volume.	356–361	6188.7–6183.7
	Basalt/clastic sediments, pale yellowish-brown (10YR 6/2). WR (i.e., unsieved whole rock) sample made up of clayey gravel (GC) with sand, and gravel (up to 3.5 cm) in clayey sand matrix, angular clasts mostly mudstone and vesicular basalt. Transitional interval; contact with underlying Puye Formation estimated at 362 ft bgs.	361–366	6183.7–6178.7

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf Puye Formation	Volcaniclastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/1), angular gravel (up to 3 cm). WR/+10F: 98% lithic clasts made up of various porphyritic volcanic (dacite, latite) rocks; less than 1% basalt clasts.	366–371	6178.7–6173.7
	Volcaniclastic sediments, sand with gravel (GW), light brownish-gray (5YR 6/1), fine to coarse sand with gravel (up to 3 cm), subangular to subrounded clasts. +10F: most clasts of dacite and latite composition, commonly silicified.	371–381	6173.7–6163.7
	Volcaniclastic sediments, gravel (GW) with sand, light gray (N7), angular to subrounded clasts. WR/+10F: 100% volcanic lithic clasts including dacite and latite, strongly silicified.	381–386	6163.7–6158.7
	Volcaniclastic sediments, sand (SW) with gravel, light brownish-gray (5YR 6/1), medium to coarse sand with pebbles (up to 3 cm), angular to subrounded. WR/+10F: 100% volcanic lithic clasts including dacite and latite exhibiting strong silicification.	386–390	6158.7–6154.7
	Volcaniclastic sediments, sand (SW) with gravel, light gray (N7) to brownish-gray (5YR 6/1), fine to coarse sand with pebbles (up to 2 cm), angular to subrounded clasts. WR/+10F: 100% volcanic lithic clasts including dacite, latite; most exhibit strong silicification.	390–402	6154.7–6142.7
	Volcaniclastic sediments, sand (SW) with gravel, pale brown (5YR 5/2), fine to coarse sand with pebbles (up to 5 cm), subangular to rounded clasts. +10F: 100% volcanic lithic clasts including quartz-rich dacite and latite; strong secondary silica alteration.	402–407	6142.7–6137.7
	Volcaniclastic sediments, gravel (GW) with medium to coarse sand, pale brown (5YR 5/2), pebbles (up to 2 cm), subangular to subrounded clasts. +10F: 95% dacite and latite clasts, minor pumice, trace hornblende; many clasts are strongly silicified.	407–412	6137.7–6132.7
	Volcaniclastic sediments, gravel (GW) with medium to coarse sand, dark yellowish-brown (10YR 4/2), subangular to subrounded clasts. +10F: 100% volcanic lithic clasts, including dacite and rhyolite; most exhibit strong silicification.	412–417	6132.7–6127.7
	Clastic sediments, sand (SW) with gravel, moderate brown (5YR 4/4), pebble gravel (up to 1 cm), subrounded to rounded clasts. WR/+10F: 98% volcanic lithic clasts including biotite- and hornblende-rich dacite, minor fine-grained sandstone; approximately 50% of dacite clasts exhibit strong silicification.	417–422	6127.7–6122.7
	Volcaniclastic sediments, sand (SW) with gravel, moderate brown (5YR 4/4), fine to medium sand with pebbles (up to 5 mm), subangular to subrounded clasts. +10F: 95% volcanic lithic clasts including dacite, quartz-dacite, pyroxene-dacite, rhyolite, also minor fine-grained sandstone clasts, minor pumice.	422–432	6122.7–6112.7

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf Puye Formation	Volcaniclastic sediments, sand (SW) with gravel, pale yellowish-brown (10YR 6/2), subangular to subrounded clasts. WR/+10F: 95% volcanic lithic clasts including quartz- and pyroxene-bearing dacite, pumiceous dacite, rhyolite; minor fine grained sandstone.	432–442	6112.7–6102.7
	Volcaniclastic sediments, gravel (GW) with fine to medium sand, pale brown (5YR 5/2), subrounded clasts. +10F: 80%–90% volcanic lithic clasts including quartz- and hornblende-bearing dacite, rhyolite; 10%–15% pumiceous dacite; minor fine-grained sandstone.	442–447	6102.7–6097.7
	Volcaniclastic sediments, gravel (GW) with medium to coarse sand, grayish orange-pink (5YR 7/2), subrounded clasts. WR sample: 98% volcanic lithic clasts including quartz- and hornblende-bearing dacite, rhyolite, and pumiceous dacite. +35F (i.e., sample fraction retained on No. 35 sieve): 70%–80% intermediate volcanics, 5%–15% pumice, trace mafic fragments, trace quartz crystals.	447–452	6097.7–6092.7
	Volcaniclastic sediments, gravel (GW) with medium to coarse sand, light brown-gray to pinkish-gray (5YR 8/1), angular to rounded clasts. WR/+10F: 95% volcanic lithic clasts including quartz- and hornblende-bearing dacite, pumiceous dacite.	452–457	6092.7–6087.7
	Volcaniclastic sediments, gravel (GW) with fine to coarse sand, light brownish-gray (5YR 6/1), pebbles up to (2 cm), angular to rounded clasts. WR/+10F: 98% volcanic lithic clasts including dacite, latite; minor pumice; minor mafic volcanic rocks; minor tuffaceous sandstone clasts.	457–467	6087.7–6077.7
	Volcaniclastic sediments, sand (SW) with gravel, light brownish-gray (5YR 6/1), pebbles up to 1.5 cm, angular to subrounded clasts. WR/+10F: dominantly hornblende- and quartz-bearing dacite, lesser rhyolite; pumice not present.	467–482	6077.7–6062.7
	Volcaniclastic sediments, gravel (GW) with sand, pale red (5YR 6/2), (pebbles up to 2.5 cm) with coarse sand, subangular to subrounded clasts. WR/+10F: contains 50% hornblende- and quartz-bearing dacite, 40% porphyritic rhyolite; 10% free quartz and hornblende crystals.	482–487	6062.7–6057.7
	Volcaniclastic sediments, gravel (GW) with fine sand, pale brown (5YR 5/2), pebbles up to 2 cm, subrounded clasts. WR/+10F: 95% volcanic lithic clasts including quartz- and hornblende-bearing dacite, rhyolite; minor free quartz crystals.	487–492	6057.7–6052.7
	Volcaniclastic sediments, gravel with fine to medium sand (SW), pale brown (5YR 5/2), subrounded clasts (up to 1 cm). WR/+10F: 100% volcanic lithic clasts including quartz- and hornblende-bearing dacite; many clasts silicified. +35F: at 502–507 ft bgs has approximately 50% biotite-porphyritic pumice.	492–507	6052.7–6037.7
	Volcaniclastic sediments, gravel (GW), pale yellowish-brown (10YR 6/2), pebbles up to 2.5 cm, subrounded to rounded clasts. WR/+10F: 80% volcanic lithic clasts including quartz- and hornblende-bearing dacite, 20% free quartz+hornblende crystals; dacite clasts mostly silicified.	507–517	6037.7–6027.7

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf Puye Formation	Volcaniclastic sediments, gravel (GW), grayish orange-pink (5YR 7/2), pebbles up to 1.5 cm, subrounded to rounded clasts. WR/+10F: 80% rhyolite and/or silicified dacite clasts, 20% quartz- and hornblende-bearing dacite; clasts partly Fe-oxide stained.	517–532	6027.7–6012.7
	Volcaniclastic sediments, gravely sand (SW) with silt, pale pinkish-gray (5YR 8/1), very fine to coarse sand with pebbles (up to 1.8 cm), subangular to subrounded clasts. +10F: 95% porphyritic dacite, quartz-bearing dacite (clasts locally silicified), minor andesite. +35F: contains dacite, andesite, rhyodacite, quartz and feldspar crystals, minor pumice.	532–542	6012.7–6002.7
	Volcaniclastic sediments, gravel (GW) with sand, light gray (N7), coarse sand and pebble gravel (up to 2.5 cm) subangular to subrounded clasts. +10F: 98% porphyritic dacite and quartz-bearing flow-banded rhyodacite.	542–552	6002.7–5992.7
	Clastic sediments, sand (SW) with gravel, light medium brown (5YR 6/4), medium to coarse sand with pebbles (up to 2 cm), subangular to rounded clasts. +10F: 85%–90% porphyritic dacite, 10%–15% quartzite and granitic clasts. Note: this interval contains first appearance of Precambrian metamorphic constituents.	552–557	5992.7–5987.7
	Clastic sediments, gravelly sand (SW), pale yellowish-brown (10YR 6/2), subrounded to rounded clasts. +10F: 80%–90% porphyritic dacite, mostly silicified; 10%–15% quartzite and granitic clasts.	557–562	5987.7–5982.7
	Clastic sediments, gravel (GW) with sand, pale yellowish-brown (10YR 6/2), pebble gravel (up to 2.5 cm) with 5%–20% fine to coarse sand, subrounded to well rounded clasts. +10F: 70–80% volcanic lithic clasts including porphyritic and fine-grained dacite, minor rhyolite, minor basalt; 10%–25% quartzite and lesser granitic and metamorphic clasts (up to 2 cm).	562–582	5982.7–5962.7
	Clastic sediments, clayey sand with gravel (GC), grayish-pink (5YR 7/2), fine to coarse sand with pebbles (up to 1 cm) and 20%–30% fines, subrounded to well rounded clasts. +10F: 70–80% volcanic lithics including dacite, rhyolite, minor basalt; 10%–20% quartzite and other metamorphic clasts; 5%–10% fine-grained sandstone clasts.	582–592	5962.7–5952.7
	Clastic sediments, sand (SW) with gravel, pale yellowish-brown (10YR 6/2), subrounded clasts. +10F: dominantly dacite (mostly silicified), 5% quartzite, minor fine-grained sandstone.	592–597	5952.7–5947.7
	Clastic sediments, sand (SW) with gravel, light brownish-gray (5YR 6/1), fine to coarse sand with pebbles (up to 3 cm), subangular to rounded clasts. +10F: dominantly volcanic lithic clasts including porphyritic dacite, and silicified dacite; 5%–7% quartzite clasts.	597–602	5947.7–5942.7
	Clastic sediments, gravel (GW) with sand, grayish-pink (5YR 7/2), pebbles up to 1.5 cm, subangular to subrounded. +10F: 75%–85% porphyritic dacite; 5–15% quartzite clasts; minor fine-grained volcaniclastic sandstone.	602–612	5942.7–5932.7

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf Puye Formation	Clastic sediments, sand (SW) with gravel, grayish-pink (5YR 7/2), fine to very coarse sand with pebbles (up to 2 cm), subangular to subrounded. +10F: 80%–90% porphyritic dacite, rhyodacite, andesite; 5%–10% quartzite clasts; minor fine-grained volcaniclastic sandstone.	612–622	5932.7–5922.7
	Clastic sediments, clayey sand (SC) with gravel, grayish-pink (5YR 7/2), pebbles up to 1.5 cm, rounded to well rounded. +10F: 90% porphyritic dacite, silicified dacite, rhyolite; 5%–10% quartzite clasts; minor fine-grained sandstone.	622–627	5922.7–5917.7
	Clastic sediments, gravelly sand (SW) with clay, pinkish-gray (5YR 7/2), pebbles up to 1.5 cm, subangular to subrounded. +10F: 85%–95% porphyritic dacite, andesite; 5%–10% quartzite clasts; minor sandstone/siltstone.	627–637	5917.7–5907.7
	Clastic sediments, silty gravel (GM), pinkish-gray (5YR 7/2), pebbles up to 2 cm, subangular to subrounded. +10F: 80%–85% volcanic lithics of a variety of compositions including porphyritic dacite, silicified dacite; 5–7% quartzite clasts; 10%%–15% fine–grained volcaniclastic sandstone.	637–642	5907.7–5902.7
	Clastic sediments, clayey sand (SC), pinkish-gray (5YR 7/2), fine to coarse sand with 30–40% clay/silt. +10F: 60%–70% porphyritic dacite, silicified dacite, rhyolite; 10%–30% clay-cemented volcaniclastic sandstone clasts; 3%–7% quartzite clasts. Interval characterized by abundance of volcaniclastic sandstone/siltstone and clayey matrix in WR samples.	642–662	5902.7–5882.7
	Clastic sediments, clayey sand (SC), light pinkish-gray (5YR 7/2), fine to coarse sand with 40% clay/silt, 5% pebbles (up to 2 cm) that are rounded to well rounded. +10F: 75%–85% porphyritic dacite, rhyolite or silicified dacite; 5%–10% quartzite clasts; minor fine-grained volcaniclastic sandstone.	662–672	5882.7–5872.7
	Clastic sediments, clayey gravel (GC), light pinkish-gray (5YR 7/2), pebble gravel with 20%–30% clay/silt. +10F: 50%–70% clay/silt clasts and carbonate-cemented sandstone; 20%–40% porphyritic dacite, rhyodacite; 5%–10% quartzite clasts.	672–682	5872.7–5862.7
	Clastic sediments, clayey gravel (GC), light pinkish-gray (5YR 7/2), pebble gravel with 20%–30% clay/silt. +10F: 30%–70% carbonate-cemented volcaniclastic sandstone, 40%–50% volcanic lithic clasts, dominantly dacite, rhyodacite; 3%–7% quartzite clasts.	682–697	5862.7–5847.7
	Clastic sediments, clayey sand (SC) with gravel, pale pinkish-gray (5YR 7/2), fine to coarse sand with 30% clay/silt, 10%–20% pebbles that are subrounded. +10F: 40%–50% volcanic lithics, mostly dacite and rhyodacite; 20%–40% carbonate-cemented volcaniclastic sandstone; 3%–10% quartzite clasts.	697–717	5847.7–5827.7
	Clastic sediments, clayey sand (SC), light pinkish-gray (5YR 7/2), fine to coarse sand with 50% clay/silt, 10%–15% pebbles (up to 7 mm) that are subrounded to rounded. +10F: 70%–80% porphyritic dacite, silicified dacite, rhyodacite; 10%–15% carbonate-cemented fine-grained volcaniclastic sandstone/siltstone; 3%–5% quartzite.	717–732	5827.7–5812.7

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf Puye Formation	Clastic sediments, clayey sand (SC) with gravel, light pinkish-gray (5YR 7/2), fine to coarse sand with 30%–40% clay/silt, 20% pebbles (up to 2 cm) that are subrounded to well rounded. +10F: 40%–50% porphyritic dacite, rhyodacite; 30%–50% carbonate-cemented fine-grained volcaniclastic sandstone; 3%–7% quartzite.	732–742	5812.7–5802.7
	Clastic sediments, gravel (GW) with sand, light gray (5YR 6/1). +10F: 80%–90% porphyritic dacite, silicified dacite, flow-banded rhyolite; up to 20% carbonate-cemented fine-grained volcaniclastic sandstone; minor quartzite clasts.	742–747	5802.7–5797.7
	Clastic sediments, clayey sand (SC), light pinkish-gray (5YR 7/2), pebbles (up to 7 mm) that are subrounded to well rounded. +10F: 80%–90% porphyritic dacite, silicified dacite, rhyolite; 5%–10% carbonate-cemented, fine-grained volcaniclastic sandstone; 3%–7% quartzite. WR sample is clay rich.	747–752	5797.7–5792.7
	Clastic sediments, gravel (GW) with sand and clay, light pinkish-gray (5YR 7/2), 70%–80% pebble gravel (up to 1.7 cm), clasts subrounded to well rounded. +10F: 80%–90% porphyritic dacite, silicified dacite, rhyodacite; 5%–10% carbonate-cemented volcaniclastic sandstone; 3%–7% quartzite clasts (up to 2 cm).	752–762	5792.7–5782.7
	Clastic sediments, clayey sand (SC) with gravel, light brownish-gray (5YR 8/1), 40%–50% fine to coarse sand with 20%–30% clay/silt, 15%%–20% pebbles (up to 2 cm) that are subangular to subrounded. +10F: 90–95% varied volcanic lithic clasts, dominantly porphyritic dacite, rhyodacite; 5–10% carbonate-cemented volcaniclastic sandstone; minor quartzite clasts.	762–767	5782.7–5777.7
	Clastic sediments, clayey gravel (GC) with sand, light grayish-pink (5YR 7/2), 40%–50% fine pebble gravel (mostly less than 1 cm), clasts subangular to subrounded. 10F: 85%–95% varied volcanic clasts, including porphyritic and silicified dacite, rhyodacite, minor basalt; 2%–7% carbonate-cemented fine-grained volcaniclastic sandstone; 1%–3% quartzite.	767–787	5777.7–5757.7
	Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), 80% gravel (up to 2 cm) that is angular to subrounded. +10F: mixed volcanic clasts of intermediate to mafic composition; minor quartzite clasts.	787–792	5757.7–5752.7
	Clastic sediments, sand (SW) with gravel and silt, pale yellowish-brown (10YR 6/2), 25% pebbles (up to 2 cm) that are angular to subangular. +10F: variety of volcanic clasts of intermediate to mafic composition; 3% carbonate-cemented volcaniclastic sandstone; trace quartzite.	792–797	5752.7–5747.7
	Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), 65% gravel that is angular to subrounded. +10F: volcanic clasts, dominantly gray dacite; no apparent sandstone or quartzite.	797–802	5747.7–5742.7

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf Puye Formation	Clastic sediments, sand (SW) with silt and gravel, pale yellowish-brown (10YR 6/2), 25% gravel (up to 2.5 cm) that is angular to subangular. +10F: 98% variety of intermediate and mafic volcanic clasts; 1%–3% cemented volcaniclastic sandstone; 1%–2% quartzite.	802–807	5742.7–5737.7
	Clastic sediments, sand (SW) with silt and gravel, pale yellowish-brown (10YR 6/2), 15% gravel (up to 1.8 cm) that is angular to subrounded. +10F: variety of volcanic clasts including very fresh, black pyroxene-bearing dacite vitrophyre (interval 807–812 ft), some mafic lithics; locally up to 1% sandstone; no apparent quartzite.	807–822	5737.7–5722.7
	Clastic sediments, sand (SW) with silt and gravel, pale yellowish-brown (10YR 6/2), 35% gravel (up to 1.8 cm) that is angular to subrounded. +10F: predominantly mixed varieties of volcanic rocks; 5%–10% quartzite and granitic metamorphic clasts; trace sandstone.	822–827	5722.7–5717.7
	Clastic sediments, sand (SW) with gravel and silt, pale yellowish-brown (10YR 6/2), 25% angular pebbles (up to 1.7 cm). +10F: variety of volcanic clasts, dominantly of intermediate composition; no apparent sandstone or quartzite.	827–832	5717.7–5712.7
	Clastic sediments, silty sand (SM) with gravel, light brown-gray (5YR 6/1), 30% gravel (up to 1.5 cm) that is angular to subangular. +10F: variety of volcanic clasts of intermediate to mafic composition; trace sandstone; no quartzite.	832–837	5712.7–5707.7
	Clastic sediments, silty sand (SM) with gravel, dark yellow-brown (10YR4/2), 30% gravel (up to 2.2 cm) that is angular to subangular. +10F: 100% volcanic clasts of mixed intermediate (dacite, latite) composition and trace basalt.	837–842	5707.7–5702.7
	Clastic sediments, gravel (GW), grayish-orange (10YR 7/4), 90% gravel-size clasts that are subangular to rounded. +10F: 50% clay-rich altered amphibole-pyroxene-feldspar pumice (dacitic?); 50% various volcanic lithologies (dacite to basalt); pumices are waxy; mostly altered to clay, and apparently represent change to tephra dominated environment.	842–847	5702.7–5697.7
	Clastic sediments, sand (SW) with gravel, light brownish-gray (5YR 6/1), 25% pebble gravel (up to 2 cm) that is angular to subrounded. +10F: dominantly mixed varieties of volcanic rocks (dacite to basalt); trace altered pumice.	847–852	5697.7–5692.7
	Clastic sediments, sand (SW) with gravel and silt, grayish orange-pink (5YR 7/2), pebbles (up to 1.5 cm) that are angular to rounded. +10F: various volcanic lithologies, dominantly dacite; 3% quartzite; 3% sandstone; trace altered pumice.	852–857	5692.7–5687.7
	Clastic sediments, sand (SW) with gravel and silt, grayish orange-pink (5YR 7/2), pebbles (up to 1.7 cm) that are angular to subangular. +10F: mixed volcanic lithologies, dominantly dacite with a minor amount of mafic lithics; 5%–10% strongly altered brown, hornblende-bearing pumice and white pumice.	857–862	5687.7–5682.7

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf Puye Formation	Clastic sediments, gravel (GW) with sand, white (N9) to very pale orange (10YR 8/2), 80% pebbles (up to 1.3 cm) that are angular to subangular. +10F: 40% brown altered and white pumice; 50%–60% dacite volcanic clasts; minor amount cemented sandstone clasts.	862–867	5682.7–5677.7
	Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), 65% pebbles (up to 2 cm) that are angular to subrounded. +10F: contains dominantly mixed varieties of volcanics (dacite, latite); 1% pumice in lower 5 ft.	867–877	5677.7–5667.7
	Clastic sediments, silty sand (SM) with gravel, grayish orange-pink (5YR 7/2), 35% pebbles (up to 2 cm) that are angular to subrounded. +10F: contains dominantly mixed varieties of volcanics (dacite, latite); 2%–5% cemented sandstone clasts; 2%–5% altered pumice; 1% quartzite in lower 5 ft.	877–887	5667.7–5657.7
	Clastic sediments, sand (SW) with silt and gravel, pale yellowish-brown (10YR 6/2), 45% pebble gravel (up to 2 cm) that is angular to subrounded. +10F: mixed varieties of volcanic lithologies, dominantly dacite; minor amounts of pumice and quartzite.	887–892	5657.7–5652.7
	Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), 70% pebble gravel (up to 2.3 cm) that is angular to subrounded. +10F: dominantly mixed varieties of dacitic volcanics; 5%–10% altered white pumice; trace quartzite.	892–902	5652.7–5642.7
	Clastic sediments, sand (SW), pale yellowish-brown (10YR 6/2), 10% pebble gravel (up to 2 cm), clasts angular to rounded. +10F: mostly dacite lithics; 5%–10% quartzite; 5%–10% indurated sandstone clasts, trace altered white pumice.	902–907	5642.7–5637.7
	Clastic sediments, sand (SW) with clay and gravel, light brownish-gray (5YR 6/1), 80% pebbles (up to 1.8 cm) that are angular to subrounded. +10F: mostly dacite volcanic lithics, trace pumice, trace amounts cemented sandstone clasts.	907–917	5637.7–5627.7
	Clastic sediments, sand (SW) with gravel, pale brown (5YR 6/1), subangular to subrounded clasts. +10F: mixed volcanic lithologies including rhyolite, hornblende-dacite; trace sandstone; trace pumice.	917–922	5627.7–5622.7
	Clastic sediments, gravel (GW), pale yellowish-brown (10YR 6/2), pebbles (up to 2 cm) that are subangular to subrounded. +10F: mixed volcanic lithologies (dacite, rhyolite), trace cemented sandstone, trace pumice, trace granitic and quartzite clasts.	922–927	5622.7–5617.7
	Clastic sediments, silty sand (SM), pale yellowish-brown (10YR 6/2). +10F: mixed volcanic lithologies (dacite, hornblende-dacite, rhyolite), 5%–10% brown and white pumice; 1%–3% quartzite.	927–932	5617.7–5612.7

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf Puye Formation	Clastic sediments, silty sand (SM), pale brown (5YR 5/2), 60% silt, 40% fine to medium sand. +10F: 25% mixed volcanic lithologies; 60% altered pumice (clay-coated) 10%–20% coarse pumice-bearing carbonate-cemented sandstone clasts.	932–937	5612.7–5607.7
	Clastic sediments, silty sand (SM) with gravel, pale yellowish-brown (10YR 6/2), pebble gravel (up to 1.5 cm) that is angular to subangular. +10F: 75%–85% mixed varieties of volcanic rocks (dacite, hornblende-dacite); 15%–20% altered pumice with brown clay coatings; minor amounts cemented sandstone clasts.	937–942	5607.7–5602.7
	Clastic sediments, sand (SW) with silt and gravel, light brownish-gray (5YR 6/1), 25% pebble gravel (up to 1.3 cm), angular to subrounded clasts. +10F: mixed dacitic and minor mafic volcanic rocks; 40%–50% white, waxy pumice.	942–947	5602.7–5597.7
	Clastic sediments, sand (SW) with silt, pale yellowish-brown (10YR 6/2), 15% pebble gravel (up to 1.5 cm), angular to subrounded. +10F: 70%–80% altered white (waxy) and brown pumice; 20%–30% mixed volcanic clasts (dacite, scoriaceous dacite); trace pumiceous sandstone clasts.	947–952	5597.7–5592.7
	Clastic sediments, sand (SW) with silt and gravel, light brown (10YR 6/4), 20%–30% pebble gravel (up to 2 cm) that is angular to subrounded. +10F: 40%–50% dacite and silicified dacite; 20%–25% white pumice; 20%–30% strongly cemented volcanic sandstone clasts.	952–957	5592.7–5587.7
	Clastic sediments, sand (SW) with silt, pale yellowish-brown (10YR 6/2), 15% pebbles (up to 1 cm) that are subangular to subrounded. +10F: 70–80% strongly cemented volcanic sandstone clasts; 15%–20% white altered pumice; 5%–10% silicified dacite volcanic clasts, partly scoriaceous.	957–962	5587.7–5582.7
	Clastic sediments, sand (SW) with silt, pale yellowish-brown (10YR 6/2), 10% pebbles (up to 1 cm) that are angular to subangular. +10F: 60% white altered pumice; 30% strongly cemented volcanic sandstone; 10% silicified dacite volcanic clasts.	962–967	5582.7–5577.7
	Clastic sediments, gravel (GW) with sand, pale yellowish-brown (10YR 6/2), 60% pebble gravel (up to 1.7 cm) that is angular to subrounded. +10F: dominantly altered dacite volcanic lithics; 30% altered white pumice; 10% strongly cemented volcanic sandstone; trace quartzite.	967–972	5577.7–5572.7
	Clastic sediments, silty sand (SM) with gravel, grayish orange-pink (5YR 7/2), 30% pebble gravel, clasts (up to 1 cm) angular to subrounded. +10F: mainly silicified dacitic volcanic clasts; 20–30% white pumice; minor volcanic sandstone chips; trace quartzite.	972–977	5572.7–5567.7
	Clastic sediments, gravel (GW) with sand, brownish-gray (5YR 4/1), 80% pebble gravel (up to 2 cm) that is subangular to subrounded. +10F: 90% silicified dacite; 5% strongly cemented volcanic sandstone clasts; minor pumice; trace quartzite.	977–1007	5567.7–5537.7

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf Puye Formation	Clastic sediments, sand (SW) with silt and gravel, pale yellowish-brown (10YR 6/2), 20–25% gravel (pebbles up to 1.2 cm), clasts angular to rounded. +10F: 90% volcanic lithologies (silicified dacite, scoria); 2–5% altered white pumice; 2–5% quartzite; trace volcanic sandstone.	1007–1017	5537.7–5527.7
	Clastic sediments, sand (SW) with gravel, pale brown (5YR 5/2), subangular to rounded clasts (up to 8 mm). +10F: 40–50% mixed volcanic lithologies including silicified dacites and vesicular to scoriaceous olivine-basalt; 30% volcanic sandstone; trace pumice.	1017–1022	5527.7–5522.7
	BOREHOLE BH1 TOTAL DEPTH (TD) = 1022 FT BGS		5522.7

Notes:

1. American Society for Testing Materials (ASTM) standards (D 2488-90: Standard Practice and Identification of Soils [Visual-Manual Procedure]) were used to describe the texture of drill chip samples for sedimentary rocks such as alluvium and the Puye Formation. ASTM method D 2488-90 incorporates the Unified Soil Classification System (USCS) as a standard for field examination and description of soils. The following standard USCS symbols were used in the R-13 lithologic log:

SW = Well-graded sand	GM = Silty gravel	SC = Sand/clay
GW = Well-graded gravel	GC = Clayey gravel	
GP = Poorly graded gravel	SM = Silt	

2. Cuttings were collected at nominal 5-ft intervals and divided into three sample splits: (1) unsieved, or whole rock (WR) sample; (2) +10F sieved fraction (No. 10 sieve equivalent to 2.0 mm); and (3) +35F sieved fraction (No. 35 sieve equivalent to 0.50 mm).
3. The term *percent,* as used in the above descriptions, refers to percent by volume for a given sample component.
4. Color designations such as hue, value, and chroma (e.g., 5YR 5/2) are from the Geological Society of America's Rock Color Chart.

Appendix E

Westbay™ Multi-Level Sampling Diagram
(CD attached to inside back cover)